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HUMAN RESPONSE TO SONIC BOOMS: A RESEARCH PROGRAM PLAN

February 1970

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This report reviews the available physiological, psychological, and sociological data concerning human response to sonic booms. The additional research that is required to develop criteria for certification of supersonic aircraft is described in conveniently workable units. Our recommendations include the relative priorities and the appropriate sequence of accomplishment of these units. The recommended research areas are: physiology - sleep interference and stress-induced disease; psychology - startle, judged annoyance, and task interference; and sociology - attitudes, complaint behavior, group action, and possible effects of the boom on social structure.

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ABSTRACT

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FOREWORD

This work was conducted by Bolt Beranek and Newman Inc. under contract with the Federal Aviation Administration, during the period from April to November 1969. The principal investigator was Dr. John A. Swets, the project coordinator was Dr. Peter A. Franken, and the technical monitor for the FAA was Mr. Raymond Shepanek. The project framework was determined jointly by these men and by Drs. Leo L. Beranek, Sanford Fidell, William J. Galloway, and Glenn Jones of Bolt Beranek and Newman Inc., Dr. Raymond Bauer of the Harvard Business School, Dr. Hallowell Davis of the Central Institute for the Deaf, Dr. John D. Dougherty of the Harvard School of Public Health, Dr. Alvin W. Gouldner of Washington University, Dr. David M. Green of the University of California at San Diego, Dr. S. Smith Stevens of Harvard University, and Dr. Harold L. Williams of the University of Oklahoma.

Authors of specific material in the report are:

Sleep	– Dr. Williams
Stress-Induced Disease	– Dr. Dougherty
Startle and Annoyance	– Dr. Green
Task Interference	– Dr. Fidell
Sociology	– Dr. Jones (with contributions from Dr. Gouldner and Dr. Jean S. Kerrick)

INTRODUCTION AND SUMMARY

In July 1968 Congress passed Public Law 90-411, which charges the Administrator of the Federal Aviation Administration to "prescribe and amend such rules and regulations as (he may find) ... necessary to provide for the control and abatement of aircraft noise and sonic boom ..." In fulfilling this duty, he shall "consider relevant available data related to aircraft noise and sonic boom."

This report examines one aspect of supersonic aircraft, namely, the response of humans to sonic booms. A knowledge of this response is an important part of the information involved in such matters as aircraft certification.

The subject of human response to sonic booms is considered in relation to three interrelated areas: physiology, psychology, and sociology. Reviews of the literature in each of these areas provide sufficient information to suggest the additional research that should be brought to bear upon the certification process. For example, information on physiological responses indicates the existence of measurable effects of sonic boom but presents no case for direct physiological damage. Therefore, the role of physiological research in the near future will be to explore the magnitude of these effects, with particular emphasis on those associated with sleep interference. Psychological and sociological research, on the other hand, has shown that sonic booms can give rise to significant individual and group response. The role of future psychological research, then, is to develop reliable measures of these responses and to relate them to the pertinent characteristics of the boom; the role of future sociological research is to determine how exposed populations will react to the boom and the interactions between the individual and the group.

The present study extends the work of earlier reviews (including those by the National Academy of Sciences, 1968, and the Department of Health, Education, and Welfare, 1969) and draws upon technical literature to develop a program plan specifying the additional research required to examine all the technical factors involved in problems of human response. The research program plan presented in this report consists of a review of current knowledge and descriptions of specific research units to be accomplished. To accommodate an anticipated schedule of certification decisions, we estimate the approximate time span required for the performance of this program plan to be three years.

The purpose of this plan is to determine the most essential information concerning human response as related to the certification process. The plan does not purport to conclude that this is the only information that would be useful. Further, it is recognized that as the planned projects are accomplished, the information derived may indicate that the subject must be pursued in greater

depth or that a particular avenue of exploration will not yield useful information.

The intent of the plan is to provide initial guidance. In some of the areas to be explored, there is little or no definitive data that may be applied to resolution of quantitative measures such as needed for aircraft certification. This is particularly true in the social interaction processes. Another example is the possibility of long term physiological effects from particular environmental stresses. Some of the specific research plans contained herein recognize the step process, but the principle of recognition of need for further study or abandonment of a particular area of exploration is inherent in the entire plan. The plan is not restricted to use by the Federal Aviation Administration. The recommended research projects will be coordinated through the Interagency Aircraft Noise Abatement Program and may be initiated by or participated in by interested agencies or industry.

The principal features of these research units are summarized below. A relative priority is given for each unit. The priorities range from 1 (based on current knowledge, this is a problem area in which more information must be gained in order to formulate an intelligent certification policy) to 3 (more information is desirable, but the problem area is not expected to be directly involved in certification decisions).

Research Units in Physiology

SLEEP

1. Waking Thresholds for Sonic Booms.
   The purpose of this unit is to determine waking thresholds and the dependence of these thresholds on various boom parameters, on time of night and stage of sleep, and on the age, attitudes, and previous exposure of the subject. This information can be used to estimate the degree to which booms will disrupt sleep.

   Priority: 1 (Degree of sleep disturbance is expected to be a major concern.)

2. Sleep Loss and Its Effects on Health and Performance.
   The purpose of this unit is to determine the effects of chronic sleep loss caused by repeated waking. This study will include consideration of the effects of psychological distress, excessive fatigue, and impaired performance. This unit is conditional upon the results of the previous unit exploring waking thresholds.

   Priority: 2 (In policy decisions thresholds may be emphasized more than effects.)

STRESS-INDUCED DISEASE

1. Animal Research.
   The purpose of this unit is to study the respone of noise-sensitive laboratory animals (rabbits and rats) to repeated booms. Boom thresholds should be determined for physiologic and pathologic effects and for birth defects.

   Priority: 2 (Disease effects seem insignificant at present, but will be important if found in future research.)

2. Human Research.
   The purpose of this unit is to determine those boom levels that produce a significant physiologic response in humans, and those that produce a response equivalent to that followed by disease in animals. Parameters studied should include change in heart rate, pulse pressure, pupil size, and skin temperature. Subsequent research on animals and humans will depend, as described in the text, upon the findings of this study.

   Priority: 2 (Disease effects seem insignificant at present, but will be important if found in future research.)

Research Units in Psychology

STARTLE

1. Development of Reliable Measures of Startle.
   The purpose of this unit is to develop a measure of startle that can be used in subsequent studies. At least six measures should be explored, including eye blink, pupillary dilatation, gross bodily movement, head or neck muscle movement, and vascular changes.

   Priority: 1 (Startle is an important factor, but it has no reliable measure.)

2. Dependence of Startle on Stimulus Amplitude and Spectrum.
   The purpose of this unit is to determine the quantitative relationships between physical measures of impulsive noise and the startle measures developed in the previous unit. The investigation should include a concern for habituation to repeated exposure and the possible role of a warning cue in reducing startle response.

   Priority: 1 (The relationship of startle to stimulus parameters is fundamental in determining acceptable levels and design objectives.)

ANNOYANCE

1. Time Constant of the Ear.
The purpose of this unit is to determine the integration rules by which the intensity and duration of impulsive stimuli are related to the judged annoyance. This information will permit a direct comparison of the annoyance of impulsive sounds with that of steady-state sounds.

Priority: 1 (These rules are needed for comparisons with extensive data on subsonic aircraft noise.)

2. Effect of the Rise Time of Impulsive Sounds.
The purpose of this unit is to develop the addition rules for the judged annoyance of an impulsive sound in the frequency region from 50 to 500 Hz. Behavior in this frequency region is critical to the determination of response to typical boom signatures.

Priority: 2 (These rules are essential to development of a scale of apparent magnitude for N waves, but are not of general import for impulsive sounds.)

3. Effect of Vibratory Stimulation.
The purpose of this unit is to determine whether the presence of vibration modifies the response to a boom. We recommend a brief pilot study in this area.

Priority: 1 (Vibration effects are believed important, and no reliable information is available.)

TASK INTERFERENCE

The purpose of this unit is to determine to what extent sonic booms can interfere with the performance of basic physical and mental taks. Studies should include motor, sensorimotor, cognitive, memory, and decision-making tasks. The recommended research explores the effects of booms occuring at irregular intervals, the presence of vibration, and the possibility of delayed or cumulative effects. This information can be used to estimate the degree to which booms will disrupt everyday activities.

Priority: 2 (Task interference is believed to be a less important effect than startle.)

Research Units in Sociology

MEANING, ATTITUDES, AND INDIVIDUAL DIFFERENCES

1. Further Analysis of Existing Data.
The purpose of this unit is to construct further indices of

individual characteristics and attitudes that show a systematic correlation with annoyance. Data sources will include the St. Louis, Oklahoma City, and multi-city field surveys.

Priority: 1 (Attitudes and individual differences play a major role in determining human response.)

2. Simulation of Annoyance.
The purpose of this unit is to determine whether the correlation of annoyance with individual characteristics and attitudes (identified by previous research in Unit 1) can also be observed in a laboratory situation with a simulated boom. If so, further exploration of the factors that condition annoyance can be conducted in the laboratory setting.

Priority: 2 (Results appear uncertain.)

COMPLAINTS

1. Further Analysis of Existing Data.
The purpose of this unit is to determine further the community, boom, and personal orientations that distinguish among respondents who are not annoyed, who are annoyed, who desire to complain, and who do complain. This unit may be combined with the similar unit on meaning, attitudes, and individual differences.

Priority: 1 (Attitudes and individual differences play a major role in determining human response.)

2. Study of Individual Differences Among Complainants.
The purpose of this unit is to validate the hypotheses drawn from the analysis of existing data (Unit 1). Such validation should be accomplished through a field-survey study examining complainant characteristics in areas exposed to a range of such environmental disturbance as aircraft noise or air pollution.

Priority: 3 (Validation is highly desirable but not essential.)

3. Model of Complaint Behavior and Laboratory Studies.
The purpose of this unit is to ascertain those aspects of an environmental situation that are important in determining complaint behavior but are not dependent either on the level of the environmental disturbances or on individual differences. These aspects, which include the various costs and benefits of complaining, should be explored through laboratory tests. The results should be in a form that can be tested in a field survey.

Priority: 2 (A model is highly desirable if study of complaint systems is to yield maximum benefit.)

4. Study of Complaint Systems.
The purpose of this unit is to characterize the handling of complaints in actual situations and to test these findings against the model developed in Unit 3. The study should include airports having different methods for handling noise complaints and different policies for noise abatement. The test design should be based on the results of the three previous units, and the final result will be a validated model of complaint behavior.

Priority: 2 (The model is an important refinement that permits better predictions than can be made from existing data.)

GROUP ACTION

1. Organizational Membership and Boom Levels.
The purpose of this unit is to study the nature and distribution of the organized protest activity that occurred during the Oklahoma City boom tests in 1964, and to attempt to relate protest activity to boom levels and to characteristics of the organization members.

Priority: 1 (Existing data should be fully utilized to determine the characteristics of organized protestors.)

2. A Study of Organized and Unorganized Communities.
The purpose of this unit is to determine the differences between those communities that form abatement organizations and those communities that do not form such organizations even though they are exposed to similar environmental stimuli. The unit is divided into three phases: identifying and describing pairs of similar communities (one with and one without an abatement organization); determining differences in each community pair; and surveying community residents.

Priority: 1 (Knowledge of reasons for organized protest is fundamental for intelligent policy decisions.)

ALIENATION

We have assigned Priority 3 to each of the three research units in this program; a general knowledge of the alienation process is expected to be extremely useful in evaluating the possible effects of sonic boom levels in terms of national response, although the relationship between alienation and the sonic boom may be indirect.

1. A National Assessment of Alienation.
The purpose of this unit is to determine the degree of alienation, or separation from society, that may exist in the nation with respect to identified social phenomena at the time that

the study is undertaken. It will be accomplished by means of large-scale survey techniques. The general results will indicate the acceptance or rejection by sectors of society of specific goals. It is expected that these results will provide a fundamental understanding that will be of general interest to government and industry.

2. Effect of Abatement on Alienation.
The purpose of this unit is to determine whether the ability to abate an annoyance modifies the feeling of alienation from the system producing the annoyance. The unit will be accomplished through a laboratory experiment in which the subjects will identify with the social system and the aversive stimulus will be an unintentional by-product of a process that yields benefits to the system.

3. Effect of Alienation on Acceptability.
The purpose of this unit is to determine whether acceptability of an aversive stimulus is dependent upon the level of alienation of the person involved. This work will be accomplished through a laboratory experiment similar to that of the previous unit.

HISTORICAL RECONSTRUCTION

1. Survey of Effects on Human Beings.
The purpose of this unit is to discover and document situations involving personal injury or disruption of activity during previous experimental tests of supersonic aircraft. The effects of interest may include physiological damage, psychological disturbances, or boom-induced accidents.

   Priority: 2 (No major effects other than startle and annoyance are suggested by previous studies, but a comprehensive study should be made.)

2. Survey of Operational Procedures and Restrictions Imposed on Military Supersonic Flights.
The purpose of this unit is to examine the restrictions that have been placed on overflights of military supersonic aircraft, and to determine the governing considerations in setting these limitations. The work may be accomplished in two phases: first, reconstructing the boom-exposure pattern and the complaint and damage experience; and second, determining the development of the limitations from interviews and records.

   Priority: 1 (Military experience may represent a relatively untapped store of experience with actual boom exposures.)

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I. PHYSIOLOGY

A. SLEEP

Chronic loss of sleep may impair performance and cause psychological distress. In fact, severe disturbances of sleep precede and accompany most acute psychiatric syndromes, and complaints of sleeplessness are among the most frequent symptoms presented to the general medical practitioner.

The psychological and social consequences of sleep-disturbing stimuli are greater for middle-aged and older persons, for daytime sleepers, for the physically and mentally ill, and for other special groups than they are for the young male volunteers usually studied in sleep laboratories. Investigation of the effects of sonic boom on sleep, performance, and health should be extended to these groups.

This section outlines, and presents some background for, several research questions whose answers may be important for administrative decisions concerned with the sonic boom. To date most investigations of sleep and arousal, in addition to having used young male volunteers as subjects, have exposed the subjects to acoustic stimuli of fairly low intensity. The effects of intense, complex stimuli such as the sonic boom have not been thoroughly investigated.

Review

Waking Thresholds

All studies cited below of responses to stimulation during sleep found evidence of specificity for both stimulus and response systems. When a standard acoustic stimulus of constant intensity is used, different physiological systems have different threshold properties, patterns of response, and relations to EEG stage of sleep. Also, for a given physiological system, different classes of stimuli cause different patterns of response. Thus, the specific effects of sonic booms on the waking response should be examined.

Studies by Oswald *et al.* (1960), Zung and Wilson (1961), Williams *et al.* (1964, 1966), Goodenough *et al.* (1965), and Rechtschaffen *et al.* (1966) show that auditory thresholds of awakening during sleep are functions of several variables. These include: stimulus intensity, EEG stage of sleep, subject differences, accumulated sleep time, time of night, amount of prior sleep deprivation, and the subject's past experience with the stimuli. In general, the probability of waking increases with stimulus intensity, with background EEG frequency, with time of night, and with accumulated sleep. For low-

voltage, fast EEG stages of sleep that occur in the last half of the night, stimulus intensities no higher than 35 dB above waking-sensation thresholds can induce full arousal.

With normal aging sleep becomes light and increasingly fragmented. Specifically, by age 45 the quantity of high-voltage stage-4 sleep has diminished, and by age 60 this stage is almost entirely absent from the EEG sleep record. Thus, normal aging is accompanied by a specific kind of insomnia where sleep is broken several times a night by lacunae of waking. The only reported studies of stimulation during the sleep of aging subjects are those in the sonic-boom simulator at Stanford Research Institute. Dr. Jerome Lukas (personal communication) has stated that two elderly men showed very low waking thresholds for simulated sonic boom and that, once awakened, they remained awake for very long periods. Two children between 5 and 7, studied in the same laboratory, were easily awakened by boom stimuli but were able to go back to sleep quickly. Almost nothing is known about the effects of intense stimuli on the sleep of infants.

Stimuli that have personal significance for the subject, that carry connotations of threat, or that are identified prior to sleep as "critical" stimuli are considerably more potent inducers of arousal than neutral stimuli (see studies cited above). Pilot studies by H.L. Williams' group at the University of Oklahoma showed that among the several physical parameters of neutral acoustic stimuli, rise-decay time was most significant for determining the potency of a signal for arousal.

Adaptation

Of major importance is the degree of long-term adaptation associated with repeated exposures to sonic booms. Information on this matter is fragmentary and inconclusive. The studies of acoustic stimulation during sleep that were cited above, as well as those by Williams *et al.* (1962) and Johnson *et al.* (1965), found that most physiological responses (such as heart rate, finger pulse volume, and EEG) show little or no adaptation during sleep. Apparently, the central-nervous-system mechanisms that permit rapid habituation during waking are not available to the sleeping subject. However, in 1966 Williams *et al.* found evidence that waking responses did show adaptation over four nights of acoustic stimulation.

On the basis of anecdotal evidence, most sleep investigators would expect to find adaptation of the waking response, even to intense stimuli. Everyone is familiar with stories of soldiers able to sleep in the vicinity of artillery fire or people able to sleep in the vicinity of railroad trains, jet planes, or pile drivers; however, Dr. Jerome Lukas reports that two young males exposed to many nights of stimulation in the SRI sonic-boom sim-

ulator showed no evidence of adaptation. Apparently, thresholds for waking remained relatively constant over the entire series. Obviously, this work needs to be replicated and extended.

Sleep Loss and Performance

Acute sleep deprivation impairs performance of certain kinds of tasks. In general, jobs that require short-term memory and high-speed processing of information are extremely sensitive to small amounts of sleep deprivation. Chronic sleep loss, where the subject is partially deprived of sleep every day for many days, has not been systematically studied. However, ancedotal reports from military and industrial sources suggest that subjects who lose some sleep each night eventually develop the same impairments founds with acute sleep loss (Williams *et al.*, 1959, 1962, 1966; Williams and Williams, 1966; Wilkinson *et al.*, 1966).

Prolonged sleep deprivation can lead to transient but severe psychological disturbance in which the subject experiences vivid visual hallucinations, delusions of persecution, and disorientation for time and place (Morris *et al.*, 1960; West, 1967).

There have been no systematic studies of sleep deprivation in aging subjects, but the investigation by Williams and Williams (1966) showed that normal young men who lacked stage-4 sleep were especially vulnerable to small amounts of sleep deprivation. Stage-4 sleep, as mentioned before, is substantially reduced with normal aging. Thus, the performance efficiency and psychological health of middle-aged and older persons will most likely be particularly susceptible to chronic sleep disturbance.

Further study of the effect of sonic boom on sleep should be given rather high priority. Without doubt, interruption of sleep is particularly annoying to everyone, and people are inordinately concerned about their sleep. In fact, doctors administer barbiturates to some 20 million patients each year and stimulants, such as dexedrine, to about 10 million. Americans pay about $100 million for prescription sedatives each year – about $350 million, if over-the-counter drugs and hospital purchases are included. Our drug companies produce about 6 to 10 billion barbiturate capsules and 8 billion amphetamine capsules a year (Luce and Segal, 1966). These sleep compounds, tranquilizers, and stimulants are prescribed for patients who complain of sleep disturbance. Thus, administrative decisions that would permit a substantial increase in sleep-disturbing stimuli in the environment could affect the health and well-being of a significant portion of the population.

Recommended Research

Unit 1. Waking thresholds for sonic booms

A research program to determine the waking thresholds in naive and experienced subjects should be designed to answer the following questions:

1) Do the waking thresholds change with time of night or with EEG stage of sleep?

2) Are the thresholds systematically lower in certain populations, such as infants or aging adults?

3) Are the thresholds altered by the subject's attitudes toward or knowledge about the sonic boom?

4) Is there evidence of adaptation to repeated boom stimuli, and, if so, is the adaptation a function of the boom intensity, rise time, time of night, or individual differences such as age?

Experience in previous studies of sleep interference suggests that the experiment should include at least five levels of boom intensity and four values of boom rise time. Subjects should be exposed to the boom stimuli at a minimum of three different times of night. At least 30 subjects should be tested, with approximately equal numbers of subjects in the three age groupings of children, young adults, and elderly adults. Subjects should be provided with private rooms for most of the experiments, but the effect of having more than one subject in a room during boom exposure may be explored. Each subject should be exposed for seven nights (two nights to adapt to the laboratory situation and five nights for boom experimentation).

To conduct these studies, the investigator will require a sonic-boom simulator in which peak overpressure and rise time can be varied independently. In addition, he will require a sound-treated, electrically shielded sleeping room and appropriate EEG and polygraphic recording equipment.

The length of testing and amount of data that must be acquired and analyzed make this unit somewhat larger than most of the other research units described in this program plan. The FAA may wish to divide the work between two groups to reduce the size of individual programs, to obtain results in a shorter period of time, and to obtain some independent verification of significant results.

Unit 2. Sleep loss and its effects on health and performance

If it is established that repeated exposure to sonic booms will cause chronic sleep loss, it will be important to determine quantitatively the effects of this loss. Research should be conducted

to determine whether repeated awakenings of test subjects cause psychological distress, excessive fatigue, and/or impaired performance. As in the previous unit, the subjects should be distributed approximately evenly among the three age groups, to determine whether the effects are more noticeable in one age group than in another.

This study may utilize any acoustic stimulus that evokes full arousal from sleep. Therefore, it will not be necessary to simulate the sonic boom or to vary the stimulus parameters in a manner related to the boom parameters. The investigator will require equipment and personnel appropriate for assessing physiological and psychological state and task performance. Relevant techniques are described in the literature cited earlier. The investigator will also require a sound-treated, electrically shielded sleeping room and appropriate EEG and polygraphic recording equipment.

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B. STRESS-INDUCED DISEASE

Repeated sonic booms will create a number of problems related to the issues of economic cost and community acceptance. Among these problems will be sleep interruption, performance decrements, annoyance, and structural damage to buildings. Physiologic response and the development of stress-related disease, on the other hand, are problems of a different sort; these costs are very difficult to measure, and, indeed, people may unwittingly accept conditions that produce disease. This portion of the report presents the facts bearing on physiologic response to environmental stress and outlines the research necessary to determine safe parameters for community health during repeated exposure to sonic boom.

Assumptions

Our analysis is based on the following assumptions:

1) The sonic boom is an acoustic stimulus of such varying intensity that its physiologic effects range from harmless to destructive.

2) Public acceptance, by itself, is not a satisfactory index of the long-term effects of acoustic stimuli. (A ready example lies in the workers' acceptance of harmful industrial noise.)

3) In view of the prevalence of arteriosclerotic vascular disease and of the potentiating effect of adrenergic stimulation, the community should attempt to limit the proliferation of environmental stresses. (The facts bearing on this assumption are discussed later in detail.)

4) Only acoustic stimuli that produce extra-auditory response are regarded as significant, stressful, physiologic stimuli. (Though acoustic stimuli below this threshold may be important physiologic stresses, there does not appear to be any way to predict their long-term population effects.)

5) The community importance of a stressful stimulus must be gauged in its relation to other stresses inherent to the environment. (There would be little point for the community to adopt expensive or restrictive standards for a given stressful stimulus so long as other politically acceptable measures would reduce the overall environmental stress more economically. If a given environmental stress represents a very small fraction of the total, this fact should be considered against the cost of eliminating that stress.)

Review

Stressful Acoustic Stimuli as a Community Hazard

Only recently has noise become a recognized community pollutant (Dougherty and Welch, 1966). While high noise levels have always been characteristic of industrialized nations, the areas of high noise density were previously well localized. It was once possible for noise-sensitive individuals to move to areas of relative quiet. Today, a growing segment of the population departs home every day for school or work. These individuals undergo a marked rise in noise exposure over that experienced in previous patterns by individuals who walked to work or school and by women who largely remained at home. The increased use of jet transportation has also raised community noise levels, the greatest rise being in urban areas. Until recently, almost all investigators have been concerned with the annoyance, decreased efficiency, and possible hearing loss associated with high noise levels. Only two authors have dealt extensively with the issues of environmental stress and human disease. Their studies showed certain correlations with regard to acoustic stress in humans but did not demonstrate causal effects.

Rosen *et al.* (1962) studied noise levels as they relate to hearing loss and cardiovascular disease. Finding very low noise levels in the environment of African Maaban natives, who had excellent hearing and a low prevalence of cardiovascular disease, they hypothesized that the low level of environmental acoustic stress was related to the natives' excellent physiologic state. This hypothesis was supported by Lapiccirrela (1966), who found low levels of catecholamine excretion in nomadic African natives.

Raab (1966) pointed out the harmful effects of adrenergic stimuli, particularly in combination with high levels of adrenocortoids. Previously, he reported myocardial infarction in individuals with normal coronary arteries whose myocardial catecholamine levels were extraordinarily elevated after emotional upset (Raab, 1943, 1944). In addition, normal coronary arteries are not uncommon in patients who have angina pectoris (Demany *et al.*, 1967).

Since a causal relation between noise and human heart disease has not been demonstrated, the evidence that relates acoustic stress to the development of heart disease is reviewed here in some detail. Unfortunately, very little work has been done on the physiologic effects of startle, and we found no studies that related startle to pathologic changes. In fact, most of the studies cited have dealt with the effects of intermittent noise stimuli.

In this section, therefore, we also discuss the causal relation between emotions and cardiovascular disease, because acoustic trauma activates the same nervous and hormonal pathways.

Physiologic Response to Intermittent Noise Stress

Very little information is available about human physiologic response to intermittent acoustic stress or startle. Finkle and Poppen (1948) studied the response of human volunteers to intense (120 dB) jet-engine noise. Aside from temporary shifts in hearing and hematologic changes, they found no signs of a physiologic response. However, the conditions of the study were poorly controlled and, with only occasional exceptions, the subjects' ear defenders were sufficient to prevent a temporary shift in auditory acuity. Therefore, the degree of their subjects' exposure to acoustic stress is not known.

Farris *et al.* (1945) found hypertension in rats subjected to the noise of sandblasting. Such high noise levels are not needed to produce a physiologic response, however. Geber *et al.* (1966) studied the effect of noise with a mean of 83 dB on rats and found a significant increase in heart weight after three weeks of intermittent exposure.

Subendocardial hemorrhage and infarction have been experimentally induced in animal hearts by direct infusion of catecholamines (Raab, 1963), stimulation of the stellate ganglion (Kaye *et al.*, 1961; Jedeneeva, 1960), and electrode stimulation of the hypothalamus (Melville *et al.*, 1963), all of which cause accumulation of catecholamines in the heart (Shkhvatsabaya and Menshikov, 1962). Similar lesions have appeared in the myocardium of mice after stress from emotionally charged noise or from the combination of white noise and frustration. These effects of environmental stress are not restricted to lower animals. Megakian *et al.* (1956) produced similar infarcts in baboons who were severely frustrated. Similar results were noted by Cherkovitch (1959) and also by Groover *et al.* (1963).

Of course, catecholamines are not the only hormones important to stress-related disease. The adrenal cortex also responds to acoustic stimuli. Henkin and Knigge (1963) found a marked increase in the cortiocosterone contents of a rat after presentation of a 22-Hz tone with a mean level of 130–135 dB. These effects, however, were not found after destruction of the organ of Corti. With much lower levels of intermittent noise (a mean of 83 dB), Geber *et al.* (1966) found significant differences in adrenal ascorbic acid, cholesterol, and eosinophil levels. The synergistic action of corticosteroids and catecholamines upon stress-related myocardial infarction has been well known since Selye's (1958) original studies. Under the action of adrenocorticoids, the heart is markedly sensitized to the necrotizing effects of catecholamines.

Environmental stress is clearly related to an increase in lipid levels. Friedman *et al.* (1967), using 102-dB noise with intermittent 114-dB 1-second peaks, studied the effects of this noise on rabbits and rats fed an atherogenic diet. Only slight changes were found in the animals experiencing no added noise stress, whereas the stressed animals showed an earlier rise in cholesterol followed

by fatty deposits in the iris and the aorta. Peculiarly, the addition of adrenalin abolished the lipid deposition in these animals, although catecholamines usually increase lipid levels during stress (Raab, 1966). Similar differences from control animals were found by Gunn *et al.* (1960), after direct electrode stimulation of the hypothalamus of rabbits fed with sunflower-oil diets. The hypothalamic stimulation was graded by the change in diameter of the rabbit's pupil with an increase in current, until the rabbit's pupil became dilated. Though the animals usually became somewhat more active during the stress interval, no significant change in blood pressure was found. Therefore, these vascular changes occurred from a stress in the central nervous system that did not cause even transient changes in blood pressure.

Krivitskaya (1964) studied changes in the central nervous system of rats and rabbits after noise of 80 to 130 dB. These sounds led to behavioral changes in the animals and to structural change in the central nervous system. He discovered that irreversible dystrophic change occurred in the central nervous system before changes were found in the acoustic nerve.

The effects of acoustic stress in pregnant animals have also been studied. Geber (1962) noted that the fetal cardiovascular system responded to pure-tone stimuli delivered to anesthetized maternal dogs, sheep, and rabbits. Geber (1966) also studied the effects of chronic audiovisual stress upon pregnant rats and rat fetuses. The stress used was sufficient to cause a loss of 2 to 6% in body weight and, in the older maternal rats, an increase of 12% in heart weight. He also found significant difference in the reproductive rate: the stressed group delivered 39% fewer fetuses.

The most striking changes occurred in the malformation rates of rat fetuses. In his control groups, only 22 malformations were found in 4,880 fetuses for a rate of 0.45%. Of a group of 3,052 exposed fetuses, 579 were malformed for a rate of 19.0%. Geber's findings have been confirmed by his personal communication with Hideo and Array.

Human response to acoustic stress has been studied, but only the most basic physiologic measures have been used to record the startle response. Landis and Hunt (1939) used motion cameras to record the timing of overt manifestation of startle following the stress of a .38-caliber pistol shot fired indoors. They found the first response to be an eye blink. This aspect of startle remained unchanged by habituation, even in target-range instructors. The second phase of startle behavior involved body movement, acceleration of the pulse, and dilation of the pupil. Such dilation, with a reactive hyperopia, has since been confirmed by Roth (1966). Landis and Hunt found that most subjects lose the second series of responses after a number of exposures; however, eye blink is never lost.

The most emotionally ill subjects studied by Landis (catatonic schizophrenics) became highly agitated after this stress. This

startle sensitivity in the emotionally ill has also been confirmed. Connors and Greenfield (1966), studying habituation of motor startle in anxious and restless children, found that hyperactive children showed poorer voluntary control over startle.

Letters written to the FAA during the sonic-boom test program at Oklahoma City revealed an extraordinary reaction to the sonic boom. Some described a reverse form of habituation in which the writer appeared to tolerate the boom less well with subsequent exposure. Writers of these letters seemed to interpret the sonic boom as a threat that was unapparent to the general public.

Jansen (1969) used intermittent, non-startling acoustic stimuli to provoke a physiologic response in humans. Above a threshold of about 70 dB, he observed pupillary dilatation and increased pulse pressure; the magnitude of both responses was related to the sound-pressure level of the stimulus. Other authors have found 70 dB to be a threshold for heart rate and pulse volume change (Field, 1967; Steinschneider *et al.*, 1966; Uno and Grings, 1965).

Oken (1966) investigated the similarity of the human response to white noise and to danger. He found the responses quite similar, except that larger changes occurred with danger and pulse pressure increased with an increased diastolic pressure. With noise, a fall in diastolic pressure contributed to the increased pulse pressure.

Takahashi and Kyo (1968) investigated noise stress in families who lived near noisy airfields. They found an increased rate of premature births and a depressed weight gain in the younger children exposed to noise. We note that no corrections were made in this study for socioeconomic status or diet.

Discussion

The experimental studies of animal response to acoustic stimuli have demonstrated a causal relation between stressful noise and a number of dystrophic processes. Human subjects who are exposed to intermittent stressful noise exhibit a physiologic response quite similar to that seen in the experimental animal before permanent changes are found. Some authors (Kangelart *et al.*, 1966), studying the health of individuals who undergo stressful noise exposure, have found higher morbidity rates, or impaired growth and development. However, no well controlled studies of human morbidity were found in a search of the literature.

In general, the question of sonic-boom habituation remains unsettled in both animal and human experiments. Basic questions of the threshold level for animal and human physiologic response have not been resolved. Certainly, the degree of response to unfamiliar,

auditory, startling stimuli undergoes some adaptation. For example, the wild deer herds at Eglin Air Force Base showed no apparent response to very high intensity sonic booms from aircraft on low-level bombing runs (Hubbard, 1968). Unfortunately, the degree to which the physiologic response becomes adapted to repeated startle is unknown.

Recommended First-Round Research

Unit 1. Animal research

The response of noise-sensitive laboratory animals to repeated (40-50 per day) simulated sonic booms should be investigated to determine the boom threshold for the following disorders:

(a) Hypertension, increased heart weight, and subendocardial fibrosis and necrosis. Sprague-Dawley white albino rats may be considered for use in this experiment. The final choice of animals to be used as test subjects should be made jointly by the investigator and the program reviewers, who may, for example, consider using "spf" (specific pathogen free) animals. The number of subjects should be sufficient to terminate the experiment with 50 controls and 50 in each cell, with a daily exposure over a period of 12 months.

(b) Atherosclerosis. The subjects in this case should be male New Zealand white rabbits. The number of subjects should be sufficient to terminate with 10 controls and 10 in each cell. The number of cells, as in (a) above, should be determined jointly by the investigator and the program reviewers. The appropriate number of cells is likely between 5 and 15, yielding dose-response curves based on from 50 to 150 animals. All rabbits should be fed an atherogenic diet over an 18-month period with daily boom exposure.

In these experiments the short-term physiologic effects of boom should be recorded for correlation with the pathologic effects. The physiologic parameters should include: change in activity, weight, skin temperature, pupil size (rabbits), and pulse pressures (rats). Though these recommendations assume that thresholds for both physiologic and pathologic changes can be determined, these thresholds may overlap or be inseparable.

The information obtained about boom thresholds for physiologic and pathologic effects should then be used to determine the boom threshold for birth defects in rats. Hopefully, such use of the information would allow a limit in the number of cells; ordinarily, the low order of rat birth defects (0.5%) would require cell sizes of 1000 offspring to detect an increase in relative risk of defect of 2 to 3 times.

Study of birth defects then would require about 10 to 12 months for rearing the rats in a boom environment and for studying mating habits and harvest of offspring. One thousand offspring should be anticipated in the control group and in each cell. Boom exposure should be 40-50 per day from birth, and continued exposure should extend until the harvest of offspring near term, after the method of Geber (1966, 1967).

Unit 2. Human research

Human research should begin with a study of physiologic response in those individuals who find the sonic boom least acceptable. At a minimum the physiologic parameters should include change in heart rate, pulse pressure, pupil size, and skin temperature. Since the sonic boom would be a long-term stress, subjects should first undergo a period of habituation that will allow the initial sharp response to decay to the apparent baseline. No data are available with regard to the proper duration of the habituation period. Of course, negative habituation could occur and possibly lead to subject withdrawals. A population size of 50 is required, with each subject acting as his own control.

Study of human beings, ideally, would determine two thresholds of physiologic response:

(a) The boom threshold that regularly produces a statistically significant physiologic response.

(b) The boom threshold that produces a physiologic response equivalent to that which leads to disease in animal studies. (This goal can be determined only so far as qualitative and quantitative comparisons can be drawn between animal and human response — again, the two thresholds may overlap.)

Recommended Second-Round Research

Subsequent research will depend upon the conclusions reached in the initial studies of animals and humans. These studies may lead to one of three conclusions:

1) The expected operational boom levels are below the level required for physiologic response in humans, or these levels cause a physiologic response no greater than that found by Jansen with 70-80 dB noise.

2) The expected boom levels elicit a regular physiologic response in humans, but no clear decision can be reached with regard to the ability of these sonic-boom levels to cause disease in animals, or no clear decision can be reached with regard to the applicability of animal results to humans.

3) The expected operational boom exposure appears to exceed in humans the threshold for physiologic change that leads to disease in animals.

Given first conclusion

In the case of the first conclusion to the initial research, the thresholds for physiologic response found in boom-sensitive individuals should be confirmed in the general population. This confirmation would demonstrate that no significant, additional, community stress would result from operational sonic-boom exposure.

This work should be conducted by the same group performing the first-round human research.

Given second conclusion

In the case of the second conclusion, further animal research should be performed, since the first-round research would leave the main issue of pathologic change unanswered. In addition, the initial research would have two important weaknesses: 1) the qualitative and quantitative measures of "equivalent" physiologic response may be in error or 2) assuming an accurate "equivalent" index, an important species difference could exist between human and lower-animal susceptibility to acoustic stress.

Therefore, in the case of the second conclusion, the boom threshold for pathologic change in primates should be determined. This research would be expensive with regard to both time (necessary to develop stress-related disease) and money (number of primates to confirm the threshold for birth defects). The following disorders should be investigated:

(a) Hypertension, increased heart weight, and subendocardial fibrosis and ischemia. This research is best performend on squirrel monkeys (saimiri sciureus), in sufficient numbers to terminate with 30 controls and 30 in each cell, with boom exposure of 40-50 per day from birth for six years. (If these animals prove difficult to obtain in such numbers, this study might make use of some of the animals used in the study of birth defects described in (c) below. An alternative, less desirable in our view, is to give up the monkey's relatively high position on the evolutionary scale in a trade for ready availability, and to use, for example, marmosets.)

(b) Atherosclerosis and myocardial fibrosis. This research should be performed on monkeys (macaca irus) in sufficient numbers to terminate with 20 controls and 20 in each cell, with boom exposure from birth for six years. All animals are to be maintained on an atherogenic diet to produce a mean cholesteral of 260 to 275 mg.

(c) Birth defects. Studies of birth defects in primates are rare; thus, little information is available with regard to the prevalence and type of primate birth defects. However, the squirrel monkey (saimiri sciureus) suffers a fetal wastage and stillborn rate of 33%. Thus the stillborn rate of this animal would appear to be useful in a study of acoustic stress. If boom exposure does not substantially reduce fertility rates, the monkey should be reared and mated in the boom environment with subsequent exposure to term. Sufficient numbers of subjects are required to produce 60 controls and 60 in each cell (both live and stillborn). This research can be performed with a considerably lower level-of-effort, if the primates are not raised in a boom environment.

If primate studies show no stress-related disease with expected boom exposure levels, and human response to the boom does not exceed the threshold for animal disease, no further study of disease causation would appear justified. Sonic-boom exposure should then be considered on a par with other objectional features of industrialized society that have no apparent causal association with disease.

On the other hand, primate research could demonstrate a susceptibility that was not detected by lower-animal research. Such a result would warrant further human research, as would the results in conclusion 3 in the first-round research.

Given third conclusion

In the case of the third conclusion, further research would be mandatory to estimate the impact of sonic-boom exposure upon community health. Such human research would be very complex, primarily because of the lack of data that define the relation of stress-induced physiologic change to the development of disease.

At a minimum this research would involve studies of catecholamine and free-corticosteroid blood levels. Both are tedious and difficult procedures, even with automated laboratory procedures. A number of more simple procedures should also be performed, such as pepsinogen blood lipids and cholesterol levels.

However, the health decrement associated with sonic-boom exposure can be gauged only by the relation of sonic-boom effects to other stresses inherent to society. To make such a comparison, human hormonal response to the boom should be studied in relation to variation of human response to the background stress of our society.

Of course, these parameters could be studied in small controlled populations, as in the first-round human studies, with no comparison to other stresses. However, the question would remain: Though the sonic boom is a potentially harmful stress, what is its significance in the total occupational or social stress of society?

Baseline data with regard to variation in physiologic response to all forms of community stress are not available in scientific literature. Since this information would be widely applicable to the investigation of stress-related disease, such a study should be a major effort designed to satisfy the broad needs of the scientific community. Outlining such a study is beyond the scope of this report. Therefore, if human and animal research indicates that the expected operational sonic boom will cause disease in primates or cause, in humans, physiologic change equivalent to that which leads to disease in animals, a scientific advisory panel should be created to design further human research.

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II. PSYCHOLOGY

A. STARTLE

Anyone who has experienced an unexpected sonic boom in the quiet of his home is aware that one of the most aversive aspects of the boom is not the loudness or magnitude of the intruding sound, but the surprise or startle it produces. Even after the acoustic disturbance is over and its source has been established, one experiences a series of generally unpleasant emotions that are often associated with a state of fear or panic.

These aftereffects are undoubtedly an experience of the various physiological changes that accompany any unexpected or startling stimulus. People generally find such experiences unpleasant; thus, this startle or surprise aspect of the impulsive acoustic event may be the largest contributor to a general negative reaction. We should, therefore, achieve some understanding of the nature of the startle reaction, in particular, how it depends on the physical parameters of the acoustic wave, and whether the startle reaction will adapt or habituate, given repeated exposures at various levels.

Unfortunately the background literature is relatively sparse. There is, for example, no standard way of measuring startle. One of the most extensive experiments made consisted simply of the high-speed photographing of human subjects; the films were then viewed and the responses classified as "startle" or "non-startle". Experiments on animal subjects have generally defined startle as a gross bodily movement, usually measured by detecting a large-amplitude, sudden movement of the animal's cage.

Thus, we are faced with a lack of specific information about the general physiological reaction to sudden impulsive sounds. In addition, very little is known about any gross physiological reactions caused by high-intensity continuous sound, other than those changes associated with the primary sensory receptors.

Review

Before outlining the specific research tasks that need to be undertaken, we shall briefly review the existing literature.

The most extensive study of human reaction to startle is Landis and Hunt's book *The Startle Pattern*. Although thirty years old, the book is still a primary source on the topic. Landis and Hunt's principal motive in studying these reactions is nicely summarized in the introductory chapter:

"The importance of the startle pattern is manifold. It is important *per se* as a demonstrable regularity in behavior, a

predictable element to be included in any account of the total behavioral repertoire of the individual. The fact that few such patterns have been found in the realm of emotion increases the value of this one. Moreover, any such definite and universal response contains interesting possibilities as a means to differential diagnosis, if a careful study can be made of its peculiarities in the various psychotic states, neurological disorders, and other pathological conditions. Such a complex, patterned reaction also suggests a new and stimulating approach to such basic problems of behavior as conditioning, facilitation, inhibition, and habituation. Finally, the problem of surprise or startle has long been fundamental in the study of emotion, and a continued investigation of it with this new orientation should yield much that is applicable to the field in general."

A brief description of the techniques used by Landis and Hunt will help to indicate the current gaps in our knowledge and explain the impossibility of predicting from their findings the probable reactions of subjects hearing sonic booms.

First, the startle stimulus in most of Landis and Hunt's work was a 38-caliber revolver fired at close range. It seems safe to say that whatever the scale used to measure the apparent magnitude of impulsive noise, such a stimulus is several orders of magnitude more intense than that expected from a sonic boom. The spectrum of a pistol shot is practically flat over the most sensitive portion of the auditory spectrum and has appreciable energy at 10,000 Hz. It is, therefore, both in magnitude and quality, unlike the sonic boom whether experienced indoors or outdoors.

The main measure of startle used in their experiments was the judgment of the subject's reaction as viewed from high-speed motion pictures taken at the time the subject was startled. They classified the various gross motor responses over repeated observations. A population of normal subjects was studied as were different groups of abnormal subjects, e.g., schizophrenics and epileptics.

Their description of the physiological changes accompanying startle is rather sparse, occupying only seven of the 150 pages in the book; the discussion contains no novel information.

Landis and Hunt's findings on the obviously critical topic of habituation can be briefly summarized. Even with such a massive stimulus as the pistol shot, Landis and Hunt report that some aspects of the complex of gross bodily movements showed adaptation or habituation when the stimulus was repeated. Certain responses, however, the eye blink in particular, seemed to resist habituation. Films taken of marksmen from the New York Police Department showed a continuation of the eye-blink response, even after years of repeated exposure. We should note that the marksman expects the stimulus, and therefore the failure of habituation, without the

element of surprise, is indeed impressive. The general finding is that prior knowledge of when the stimulus will occur produces less responsiveness and in no case produces a greater startle reaction.

Landis and Hunt are often quoted as supporting the position that startle does not habituate. Their exact position, however, is (p. 149): "It (startle) habituates, but never completely, more so in some individuals, more strongly at some times than at others." It is clear that this aspect of startle needs considerably more exploration.

A great deal of the work following Landis and Hunt's monumental study investigated various other techniques for measuring startle. Berg and Beebe-Center (1941) studied cardiac response. Jones and Kennedy (1951) explored electromyographic techniques. Freeman and Pathman (1942) monitored EEG. They also measured gross bodily movement by monitoring the pressure in an air-mattress on which the subject rested during the tests. The test-retest reliability of an increment in movement, as detected from the air-mattress, was 0.89. This reliability far exceeds the reliability of many of the other physiological measures just reviewed. Certainly the simplicity and reliability of this technique recommend it for further consideration.

In addition to the work with human subjects, extensive literature has been produced on the reactions of animals to sudden intense stimuli. Although the inductive leap from animal to human is often a dangerous one, the animal studies in many respects are more relevant to the sonic boom problem because the stimuli used are more similar to the boom, both in quality and level, than is the pistol shot of Landis and Hunt's study, and because the amount as well as the total duration of the exposure can be studied at more realistic values.

The 1967 article by Hoffman and Searle provides an excellent summary of much of the work on startle, especially of that performed with lower animals. In addition, having been published only two years ago, it provides a comprehensive bibliography of earlier studies. In much of the work on lower animals, the laboratory rat was used as the subject. The rat, like man, reacts to a startle stimulus with a gross bodily motion, consisting of a rapid sequence of flexor contractions that ends with a brief crouchlike posture. The typical experiment, therefore, involves placing the animal in a small light-weight wire cage and then monitoring the movement of the cage when the startle stimulus is presented.

To review briefly the main experimental findings:

1) It appears that stimuli of equal sensation level (equal decibels above the absolute threshold) produce equal startle. Thus, the "psychological magnitude" of the acoustic stimulus ap-

pears to be the crucial variable; the SPL can be as different as 140 dB at 720 Hz while only 100 dB at 13,250 Hz and yet produce equal startle (Fleshler, 1965). This conclusion is supported indirectly by Hoffman and Searle (1967).

2) The startle response habituates. Hoffman and Searle (1967), presenting 625 trials per day during an 11-hour period, measured sizeable diminution of the amplitude of the startle response over time; measuring the response over a 15-day period with 60 trials per day, they observed considerable habituation. Habituation was also observed in the studies of Moyer (1963) and Ladd and Hunter (1936). Also noted is the fact that the startle response recovers with time, if no startle stimuli are introduced in the intervening period (Brown *et al.*, 1956).

3) A potentially important practical finding is that any cue (that is, a stimulus of lesser intensity that reliably precedes the startle stimulus by as much as 20 msec) materially reduces the amplitude of the startle response. Hoffman and Searle made this observation in two separate experiments (1967, 1965).

4) If the startle stimulus is presented in a background of continuous noise, the amplitude of the startle appears to increase as the level of the background noise increases – that is, the same startle stimulus is more effective when presented in a noise background than when presented in silence (Hoffman and Searle, 1967). Why this occurs is not clearly understood and certainly appears puzzling.

5) Animals made fearful by prior electric shocks give larger startle responses, but these responses habituate more rapidly than those associated with control (no shock) animals (Brown *et al.*, 1951).

Finally, we should remark that any generalization from the rat to the human especially in the area of reaction to acoustic stimulation, is hazardous. It is well-known that some rodents, particularly mice, can be driven to convulsions by comparatively mild acoustic stimuli, e.g., the jangle of keys. This phenomenon, known as "audiogenic seizure", has been studied extensively (Frings and Frings, 1952).

Recommended Research

We urgently need to know more about what the necessary and sufficient conditions are for producing startle in human beings, how and to what extent startle habituates, and how it recovers after various periods of rest. Before any of these questions can be answered, we must develop a convenient and reliable measure, or measures, of startle. Hopefully, we can develop one measure that is sufficiently sensitive so that it will not habituate immediately and will provide a reliable indicant of startle, even if the subject is notified before the startle stimulus is presented.

Unit 1. Search for reliable measures of startle

The purpose of this research is to develop convenient, reliable, and objective measures of startle to be used in future psychophysical studies in which the parameters of the acoustic stimulus and other aspects of the startle situation are related to the magnitude of the startle produced. At least six measures should be explored, including

1) eye blink,

2) pupillary dilatation,

3) gross bodily movement,

4) movement of the head or neck muscles, recorded mechanically, optically, or electromyographically,

5) vascular changes (vasoconstriction and dilatation), monitored in whatever way the experimenter deems most reliable and convenient, and

6) other measures developed by the researcher. Though the development of any measure is essentially a bootstrap operation, the research still should be able to provide an indication of the reliability of the measures by correlation of the responses measured on odd and even trials for a single subject in a standard test sequence involving at least 30 presentations of the startle stimulus. Reliability should also be assessed by measuring the repeatability of the same sequence of measurements taken on the same subject on two separate occasions. The interval of time between the two test-sessions should be at least 24 hours.

At least 20 subjects should be tested, including male and female subjects of various ages, 50-years and older, 30 to 50 years, and college-age.

Three well-controlled startle stimuli should be used. The first should be of sufficient magnitude to induce startle on most occurrences, for example, a simulated pistol shot. The magnitudes of the second and third stimuli should be chosen to produce less startle.

Hopefully, some or all of the measures of startle developed in this program will vary reliably with the apparent magnitude of the acoustic stimulus. This evidence might be adduced by correlating the magnitude of the startle with the magnitude of the impulsive stimulus, or by correlating the verbal reports of the subject (rating the "startle" of the stimulus) with the objective measures.

Whatever measures of startle are finally developed, at least three of them should be used in a series of test sessions lasting

at least five days. The startle stimulus in these tests should be repeated ten times in an hour session. The purpose of the last test is to assess whether or not the measure shows habituation and, if so, to what extent.

It is hoped that of these three measures at least one will be largely resistant to habituation and that at least one other will clearly indicate a diminution of response over retested application of the startle stimulus.

If possible, the search for reliable measures of startle should be pursued by two independent laboratories. In the case that different methods of measuring startle are developed, each laboratory should then be asked to test the different methods in a parallel test sequence to establish the reliability of the measure across laboratories.

Unit 2. Dependence of startle on stimulus amplitude and spectrum

Assuming that Unit 1 has developed a set of reliable measures of startle, these measures could then be used to determine which aspects of the acoustic stimulus are effective in producing startle. This information will be useful for engineering-design objectives; e.g., so that the plane's sonic-boom signature or the house rattle will produce minimum startle.

First, the shape of the family of equal-startle contour curves should be determined. By analogy with equal-loudness and equal-noisiness contours, an equal-startle curve is a frequency spectrum, each band of which contributes equally to the startle response. The stimulus should probably be octave, or possibly one-third octave, bands of noise presented at brief durations of 100 msec or less. The number of subjects used in the experiment and the duration of the testing will have to be determined on the basis of the reliability of the measure of startle. The aim should be to know the equal-startle contours to within 5 dB.

The next aim should be to determine if some cueing, such as a brief warning sound that reliably precedes the larger startling stimulus, will effectively diminish the startle reaction. The intensity and minimal lead time required for the effective warning signal should also be determined.

Finally, habituation and how the schedule of stimulation influences startle should be investigated. The exact course of this work will depend on some of the results gathered in Unit 1. Probably the most obvious question is whether a regularly scheduled sequence of startle stimuli produces more or less reaction than those programmed irregularly.

All of these experiments require special care with regard to the population of the subjects tested. This population must be

sufficiently heterogeneous so that one can reasonably extrapolate to the general public. Again, the age of the subjects seems to be an especially important variable: at least some of the subjects should be of middle age and a few should be elderly.

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B. ANNOYANCE

In assessing the impact of the sonic boom, we must make some attempt to relate impulsive sounds to the sounds created by conventional aircraft; otherwise, we will be ignoring both a considerable body of data already acquired on the judged annoyance or noisiness of conventional aircraft and the considerable experience already achieved in relating those data to the reaction of communities surrounding airports. Research should aim at developing a scale of apparent magnitude or annoyance for impulsive sounds that will be similar to the PNdB or Loudness-Level scale used for more continuous noise exposures. Even if this scale does not accurately relate to the "true" annoyance value (such dimensions as startle or surprise cannot be realistically simulated in the psychoacoustic laboratory), a reliable scale of the apparent magnitude of impulsive sounds would still be desirable both for further research and for correlation with complaint behavior as measured in field studies.

This scale of apparent magnitude of impulsive sounds should, at the least, take into account the variety of spectra and durations associated with impulsive stimuli and yield a measure, based on physical assessments of the stimulus, that would predict the apparent magnitude of these sounds to human observers. Secondly, the scale should be applicable to continuous, or nearly continuous, sounds so that it can be used in relation to present conventional measurements.

We therefore suggest that further research be conducted using orthodox psychoacoustic techniques that present short, impulsive stimuli to listeners and ask for their judgment of the apparent magnitude or noisiness. A question central to this research is the length of the interval during which the ear integrates acoustic power, that is, the ear's time-constant. This question of the time-constant is the crucial issue in trying to relate the apparent magnitudes of impulsive and continuous sounds. Unfortunately, so far comparatively little agreement has been reached on the size of this time-constant.

The Problem

Ideally, we would like to have a machine that would sense the acoustic pressure at some point in space and calculate a number proportional to the magnitude or loudness of the measured sound for both impulsive and continuous sounds. The calculation should be such that if an impulse of 1/100 of a second were measured to be the same as a steady-state sound of 100 seconds in duration, then human subjects listening to both sounds would, on the average, rate them equal in annoyance or noisiness.

Now, what sort of calculation can be made on the sound wave so that it will correlate with the perceived magnitude? If the sound

is an impulse, then obviously the instantaneous pressure is not likely to suit our needs; for, if the pressure peak is extreme but the duration brief, the impulse is not likely to generate much of a response, either in the movement of the eardrum or in the various structures that follow. Clearly, some quantity like the *energy* (that is, the integrated power) is more likely to correlate with the perceived magnitude. We might also wish to alter the pressure waveform by a transfer function in an attempt to mirror the operation of the various auditory structures, but ultimately, we will still calculate an energy-like quantity.

Let us now consider a continuous sound, such as a ten- or twenty-second flyover. Here again the energy in the flyover may well be the crucial quantity; however, practically all of the existing calculation procedures, with the exception of the relatively recent "effective" quantities, have ignored the duration of the sound. Perceived Noise Level (PNL), Loudness Level, A Level, and N Level, ignoring the duration of the noise exposure, basically assume a continuous, relatively steady-state, sound. No problem arises as long as the exposure durations are the same. If, for example, two sounds have equal duration, but one a greater PNL value than the other, then the former is presumably noisier than the latter, however we treat exposure duration. The problem exists because all of the previous study in this area is cast in terms of steady-state measurements. We therefore have a backlog of research that is basically ambiguous with regard to its application to transient signals. The basic quantities of the different sounds are not directly comparable since steady-state measures have dimensions of pressure or pressure-squared, whereas impulsive sounds must be expressed as energy-like quantities.

Using the Fourier transform in the calculation of the apparent magnitude of the impulsive sound does nothing to resolve this basic difficulty. The Fourier transform of the impulse, developed into a nominal one-ohm impedance, has the dimension of pressure times duration. The energy-density spectrum (the Fourier transform times its conjugate) has the dimension of pressure times duration squared. The energy-density spectrum, when integrated over some band of frequencies, then has the dimension of energy [(pressure × density)^2 × (cycles per unit time)]. Thus, whatever Fourier transformation is used, the basic dimensions are not simply pressure or pressure squared and, therefore, cannot be used for comparison. The Fourier transform will still play a significant role in the analysis of impulsive sounds, because it is the only rigorous way to discuss the frequency content of a brief waveform, but it does not resolve the basic problem.

The problem is that impulses are naturally measured in terms of energy, whereas to date measurement of conventional noise sources has been in terms of pressure or power levels, independent of duration. There is a basic ambiguity in applying practically all

of these steady-state measurements to impulsive waveforms. For example, it seems plausible that one should weight the various parts of the spectrum unequally. Energy in the region of 50 Hz should not count as much in the determination of the apparent magnitude as energy in the 1000 Hz or 2000 Hz region. But the exact frequency-weighting contour depends on the absolute magnitude of the stimulus - at least for steady-state sounds. Thus, to apply a frequency-weighting contour to impulsive stimuli, one would need to know the absolute level of the impulse. This absolute level is exactly what we are trying to determine.

One way to break the circularity is to assume that the ear integrates power over only a brief interval: namely, the ear's effective duration or time-constant. Then treating a steady-state measurement, such as the loudness level of a pure tone, as a judgment of energy rather than of power or pressure, one can simply relabel the equal-loudness contours in energy terms and apply these data to impulsive stimuli.

The simplicity and directness of this approach is widely appreciated and is evident in practically all of the proposed calculation procedures. Most of the differences among proposed procedures involve matters of detail rather than approach; unfortunately, some of these details can change the calculated values by sizeable amounts.

Because resolving this problem of the ear's time-constant offers such a simple solution to the problem of the relation between the apparent magnitude of steady-state and transient signals, we strongly urge more work in this area. Before discussing the specific suggestions, we will review the previous relevant work.

Review

Our review begins with a brief recitation of the basic experimental facts. These include such topics as estimates of the ear's time-constant, whether or not the time-constant depends on sensation level and frequency location, the effects of repetition, and the like. The review closes with a brief summary of current proposals about how impulsive sounds should be measured in order to predict their apparent magnitude.

Unfortunately, the problem has one further dimension that should be kept in mind during this review. We have fairly strong evidence that judgments about the "annoyance" and judgments about the "loudness" of impulsive sounds are somewhat different (Zwicker, 1966). This difference is especially important in judgments of repetitive, impulsive sounds and may also be responsible for many of the discrepant results found in other areas. With the exception of Zwicker's study and a recent report by Shepherd and Sutherland (1968), there is little direct evidence on this problem.

The Ear's Time-Constant

For reasons already outlined, the determination of the ear's effective duration or time-constant is an issue of fundamental significance. One of the first to investigate this problem was Békésy (1929). He used a sinusoid of 800 Hz and, by varying its duration, concluded that about 180 msec were needed for it to reach its maximum loudness. Munson (1947) used frequencies of 125, 1000, and 5650 Hz and estimated the time-constant to be about 250 msec. Miller (1948) used broad-band noise and estimated the time-constant to be about 65 msec at the higher sensation levels. Small *et al* (1962) essentially repeated Miller's experiment, but their estimated values of the time-constant are consistently smaller than Miller's estimates. At high levels Small, Brandt, and Cox estimated the time-constant to be in the range of 10 to 20 msec. Port (1963) investigated a variety of brief impulsive sounds. Most were gated noises, but of various bandwidths, center frequencies, and levels. He estimated, for a variety of experimental conditions, that 70 msec is a reasonable value of the ear's time-constant. Niese (1965), summarizing a number of studies from the Dresden laboratories, concluded that 25 msec is a good average value and argued that this estimate fits in nicely with estimates of reverberation time. In two papers Zwicker (1966a, 1966b) took issue with the conclusions of the Dresden group and presented data from the Stuttgart laboratory that was consistent with longer estimates, approximately 100 msec. Stevens and Hall (1966), using a magnitude-estimation technique, measured the time-constant at about 150 msec.

In summary, there is considerable disagreement about this basic auditory parameter. The estimates range from about 20 msec up to nearly 200 msec. Such a range amounts to about 10 dB in apparent loudness, since, for impulses shorter than this critical duration, the energy in the stimulus seems to determine its loudness. One reason for the experimental scatter is that the judgments are difficult to make. Practically all investigators comment on the difficulty of the task, and some have published data on the variability among the subjects. Garner (1949) presented complete data on six subjects: three of them showed complete energy summation up to about 300 msec; the other three yielded loudness estimates that are nearly independent of duration. At 10 msec the difference in the judgments of the two groups is about 10 dB. Reichardt *et al.* (1966) showed a distribution of judgments from over forty subjects. This distribution is essentially normal, but the range among the judgments is more than 20 dB. Given such a range of estimates, several investigators have explored various other parameters that might be responsible for the various discrepancies. Regrettably, there is also little agreement on these results.

Effects of Level of Stimulation on Estimates of the Time-Constant

Miller (1948) in his original study showed that the time-constant depended on sensation level, being about 200 to 300 msec near the

just-audible threshold and decreasing to about 65 msec at the 100-dB sensation level. Small *et al.* (1962) confirmed this influence of absolute level on the size of the time-constant though, as we previously remarked, the estimates of the time-constant were consistently smaller by a factor of about three. Port (1963), however, presented data indicating that the level of a 5-msec pulse, equated in loudness to a continuous noise, does not depend on level. This result is impossible to reconcile with Miller's results without additional, *ad hoc*, assumptions. Port concluded that his data are inconsistent with Miller's. Finally, Stevens and Hall (1966) presented data over the same range as Miller's and showed no change in a critical duration of about 150 msec, except at the lowest level, where the duration may increase to 300 msec. A level of only 10 dB above the absolute threshold level shows the 150-msec critical duration.

Obviously, the simplest assumption is that the time-constant is the same at all levels. As we have seen, two investigators can be cited to support this assumption. But, if we accept the more complicated position, what practical effect will this have on our calculation of the apparent magnitude of impulsive sounds? The essence of the problem is that an impulsive sound, such as a sonic boom, has appreciable low-frequency content. Since the ear is relatively insensitive to low-frequency energy, this energy is near the absolute threshold, and hence the time-constant should be large. At higher frequencies, however, the energy is many orders above the absolute threshold, and the time-constant should be small. Faithfully simulating the auditory system, then, may entail different time-constants at different frequencies even if the sound pressure level is fixed.

Effect of Frequency Region on Estimates of the Time-Constant

An issue closely related to the previous discussion is whether or not the time-constant is the same at all frequencies. If we are forced to a spectral analysis of the stimulus, do we need to apply different integration times to the different bands? Remarkably, there are very little data on this important question. Port (1963) appears to have been the only investigator to consider this question directly. He measured how the duration of a burst of noise influenced the apparent loudness of bands of noise at three center frequencies: 350, 2500, and 10,000 Hz. The time-constant for the two lower bands appeared to be about the same (namely 65 msec), whereas the very high frequency band, 10,000 Hz, appeared to have a much longer time-constant (about 200 msec). Over the practical audio range, however, the time-constant did not appear to depend on frequency.

Effects of Repetition of the Impulsive Stimulus

Although not strictly germane to the prediction of such single impulsive sounds as the sonic boom, one further issue has

contributed to the controversy concerning the rating of impulsive stimuli. This is the effect of roughness observed when an impulse is repeated periodically at low repetition rates. The phenomenon is that a repetitive train of noise bursts, say 10 msec on and 10 msec off, is judged about 3 to 5 dB louder than a continuous noise stimulus of equal peak level (Pollack, 1958). Since the duty cycle is 50%, the intermittent sound is about 6 to 8 dB less in energy than the continuous sound. This effect has also been replicated by Zwicker (1966), though he indicated that the effect depends on how the observer is instructed. When instructed to judge loudness and not annoyance, the observer did not express the effect; when instructed to judge annoyance and ignore loudness, however, the subject expressed Pollack's result.

The result is of more than academic interest, since it leads some investigators to believe that the time-constants of buildup or decay are not the same. Port, in particular, has suggested that the buildup time-constant equals 70 msec, whereas the decay time-constant should equal 350 msec.

Proposals for Calculating the Apparent Magnitude of Impulsive Noise

So far, various investigators have suggested four schemes for calculating the apparent magnitude of an impulsive sound, such as the sonic boom. All of these techniques can be used to calculate the apparent magnitude of continuous sounds as well. Thus, they satisfy our criterion of being a potential bridge from the experience already gained from work on noise-abatement with conventional aircraft to that needed for supersonic aircraft.

Port's proposal. Port's (1963) essential idea is to treat the ear as measuring the energy over a 70-msec interval. If the impulse is less than 70 msec in duration, one measures the energy in the impulse, calculates the effective sound level by dividing the measured energy by 70 msec, and proceeds as if the impulse were continuous. This method applies the equal-loudness contours of steady-state sounds. For repeated impulses, such as periodic pulse trains, Port advocates more complicated procedures involving a 350-msec decay time.

Niese's proposal. Niese's (1965) basic ideas are essentially the same as Port's, though the details differ. Niese assumes that the time-constant is 25 msec instead of 70 msec and treats repeated pulse trains differently. The major difference is in how steady-state measurements should be made. Niese suggests starting with an A-level calculation, corrected some number of decibels by the size and frequency of the largest 1/3-octave-band measurement. This step tries to take into account the various spread-of-masking effects. If the transient sound is a single impulse, he suggests a 25-msec integration time. If the sound is periodic and impulsive, he uses a difference between a long-term energy measurement

and the 25-msec reading to calculate a correction term. In this way, he avoids the 350-msec decay time of the Stuttgart group.

Kryter's proposal. Kryter (1969) attempts not so much to mimic properties of the ear as to develop a mechanistic calculation procedure. In this way his suggestion is similar to Niese's.

Essentially, one calculates PNL over 1/2-second intervals. If the sound is impulsive, defined as any 1/2-second interval when the overall sound pressure level changes 40 or more dB, then one corrects the basic PNL calculation, apparently for "startle". The "startle" correction is linear with the level of PNL above the background; for example, the correction is 0 if the measured PNL is 0 dB above the background and 25 dB if the PNL is 70 dB above the background.

The relation to continuous sound is not easy to summarize. Basically, one calculates PNL in 1/2-second steps, uses energy integration based on the PNL calculations, and finally adds another correction having to do with onset duration.

Johnson and Robinson's proposal. We shall treat Johnson and Robinson's (1967) proposal in more depth than the preceding suggestions, since it is most obviously relevant to sonic booms, especially the outdoor N wave. It also appears to represent the most substantial position of the British in this area. The group at Southampton has proposed some techniques that measure the impulses up to an arbitrary constant (Zepler and Harel, 1965; Pease, 1967; Rice and Zepler, 1967). Johnson and Robinson's proposal supplements these suggestions by providing a relation between the impulse calculation and steady-state sound. They deal explicitly with the problem of the equal-loudness contour at very low frequencies.

In many respects the Johnson and Robinson proposal follows Port's suggestions. First, the power in 1/3-octave bands is accumulated with a 70-msec time-constant. These energy-like quantities are converted to equivalent sound pressure levels, and the loudness is measured from the calculated numbers just as with steady-state sounds.

Complications arise when one tries to apply this technique to particular impulses, such as the N wave. To understand the nature of this problem in more detail, we need to consider the spectrum of an idealized transient signal: namely, an N wave of duration T and rise time τ. Figure 1 gives the power spectrum of such an impulse. (Ripples occur in the spectrum at a rate of 1/T, but these are small compared with the regions of frequency over which the ear integrates. We will ignore these second-order effects.) The important features of the problem, revealed in the asymptotic approximation to the envelope of the actual spectrum, are the approximate locus of the maximal energy, that is, about $1/2 \cdot 1/T$. Thus, for an N wave of 1/10-sec duration, the maxima occur at 5 Hz.

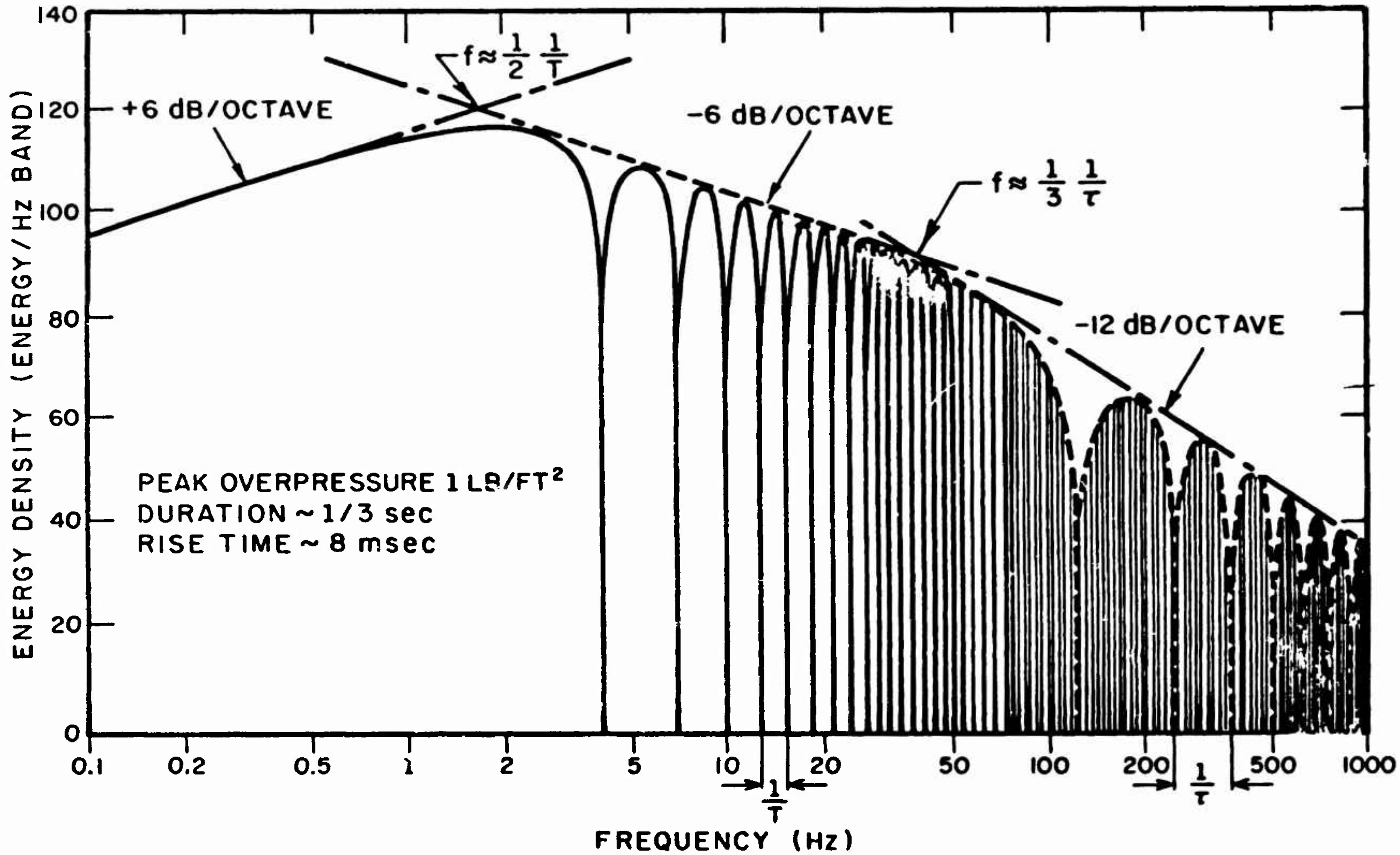

FIG.1 FORM OF POWER SPECTRUM FOR AN N-SHAPED IMPULSE OF DURATION T AND RISE TIME τ

If the duration is 1/3 second, the maxima occur near 1.5 Hz. The amplitude of the maxima, following a 6-dB-per-octave line, increases by 6 dB as one doubles the duration. The second important break-point depends on the rise time of the N wave and occurs at approximately $1/3 \cdot 1/\tau$. At that point in the spectrum, the energy begins to fall off at 12 dB per octave rather than 6 dB per octave. When compared to the frequency response of the human auditory system, the second break-point is obviously of critical importance.

Figure 2 relates this power spectrum to some basic parameters of the hearing mechanism. The solid line is the "envelope" of a 1-lb/ft^2 boom of 1/3-sec duration and of 2.5-msec rise time. The solid curved line shows the minimum audible sound pressure that can be detected in a free-field situation. In calculations of the apparent magnitude of an impulsive sound such as the N wave, the important quantities are how much the energy contributes to the loudness at the various frequency regions. Some impression of these contributions can be obtained by comparing, on a spectrum basis, the equal-loudness contours (dashed line) as taken from S.S. Stevens' proposal for the calculation of loudness (Mark VI).

As can be seen, the break in the spectrum, attributable to the rise time, causes most of the contribution to loudness to arise from the very low frequency bands. Thus, the exact form of the loudness contours at the low-frequency region, where the contours are very uncertain, heavily influences the calculated value.

Johnson and Robinson suggest special procedures in the evaluation of the low-frequency bands: "Each band pressure level below the 50-Hz 1/3-octave band is reduced by means of equal-loudness contours to that level at 50 Hz which produces the same loudness level in phons. These weighted levels are then combined with that already existing in the 50-Hz band with the normal rules of decibel additions. The resulting modified 50-Hz-band pressure level together with all the values already deduced in the 1/3-octave bands above 50 Hz provide the basic data for entering the loudness calculations."

We should emphasize that the low-frequency problem is not special to the calculation of loudness. The equal-noise contour is almost exactly parallel to the equal-loudness contour at the low frequencies; thus, the exact shape of the contour in the region below 100 Hz has a rather sizeable influence on the final value. Kryter has suggested some special rule to apply to the very low frequency bands. If using 1/3-octave bands, he suggests that the power in the 50-Hz, 63-Hz, and 100-Hz bands be added together and assigned to the band having the most power. Similar procedures are applied for the three bands at 125, 160 and 200 Hz. Also, the 250-Hz and 315-Hz bands are treated in this combined manner.

The effect of both the Kryter and the Johnson and Robinson proposals is to redefine the contribution of the low-frequency bands

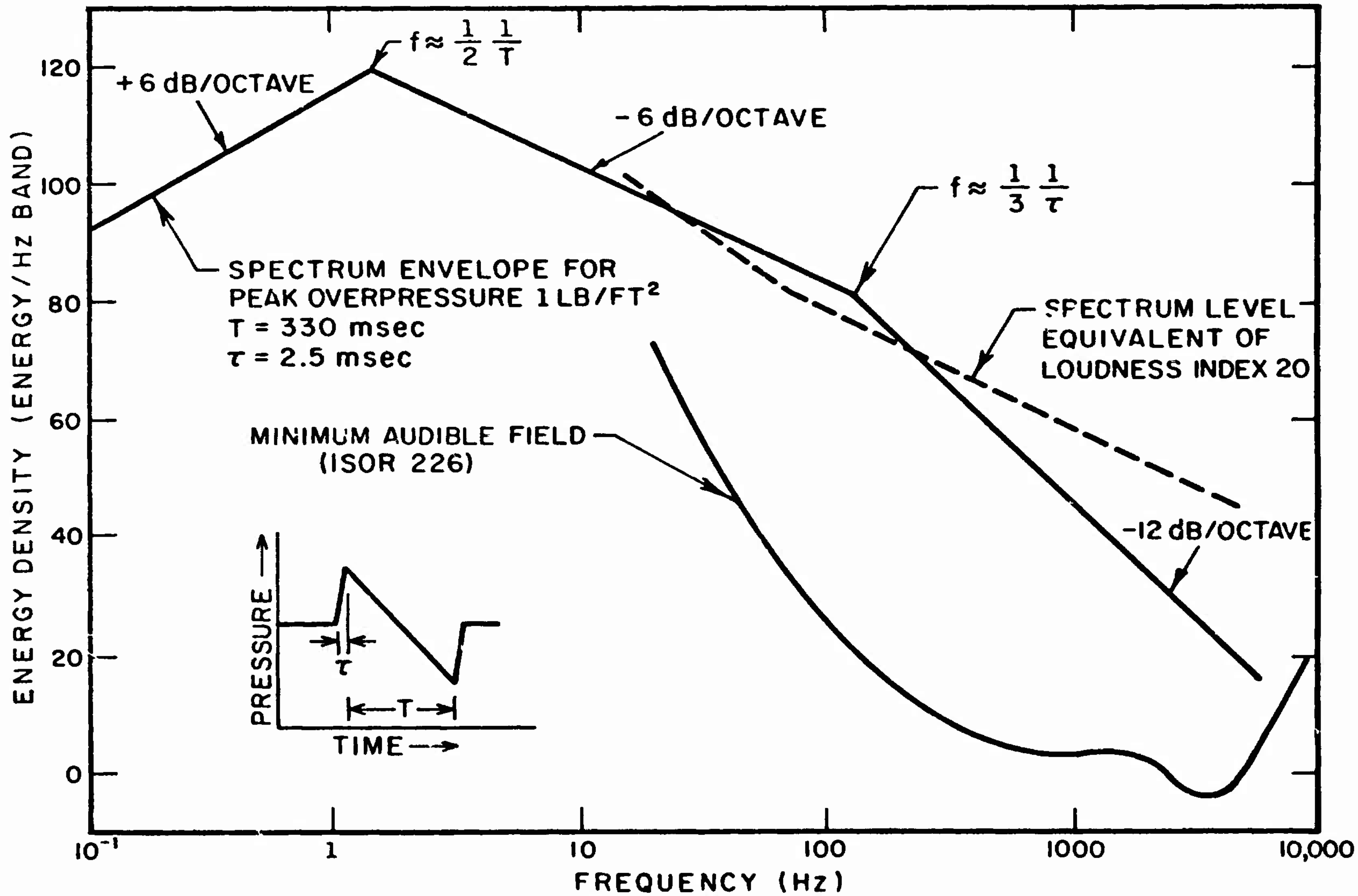

FIG. 2 RELATION OF SONIC BOOM POWER SPECTRUM TO MINIMUM AUDIBLE FIELD AND LOUDNESS INDEX 20

and to recognize that the width of the ear's filter or "critical band" is larger than the width of a 1/3-octave filter at the very low frequencies.

Rise Time and Apparent Magnitude

Given an explicit procedure for calculating the apparent magnitude of a transient signal and the explicit spectrum of an idealized transient signal, such as the N wave, one can calculate how variation in some parameter of the waveform, such as the rise time, should affect perceived magnitude. Johnson and Robinson carry out this calculation. A graph from their paper is reproduced in Fig. 3. Along with this graph we have included the results of two investigations of how rise time affects psychoacoustic judgments. The first set of data comes from the experiment by Shepherd and Sutherland (1968); the second, from Zepler and Harel (1965).

The conditions of these two experiments were quite different. Shepherd and Sutherland (1968) used loudspeakers with special low-frequency drivers to insure good fidelity in the frequency region near D.C. Their recordings of the acoustic waveforms show excellent fidelity, even of the relatively long-duration N waves. Zepler and Harel used earphones in which only the leading and trailing transients of the N wave produced noticeable excitation. Each excitation was the usual transient response of the earphone to a brief impulse. Despite the vast differences in the acoustic waveform, we would expect the data to agree since the rise-time parameter affects frequencies generally above 50 Hz. We might also note that though the calculated graph assumes a duration of approximately 1/3 sec, the form of the graph should be essentially unchanged for durations of 1/10 sec and greater, since the total duration of the N wave will affect only those frequencies below 5 Hz. Since the contribution of such frequencies to the calculated loudness is nil, such a change in duration will not affect the form of the function shown in Fig. 3.

For the simple N wave, then, we have reasonable agreement on how the apparent magnitude should be calculated, despite the disagreement over the exact value of the ear's time-constant. For such a wave, once the duration is 100 msec or longer, the total duration is not significant, only the rise time. Thus, aside from minor disagreements as to the shape of the equal-loudness or equal-noisiness contours, the calculation schemes all agree.

The Indoor Impulse

Unfortunately, the duration of the boom as heard indoors is not equal to the duration of the N wave. Before leaving the matter of calculation procedures, therefore, we must comment on the general problem and emphasize that the aim is not simply to calculate the loudness of an N wave but to develop a procedure that will be valid for impulses in general. Were our only experience of the sonic

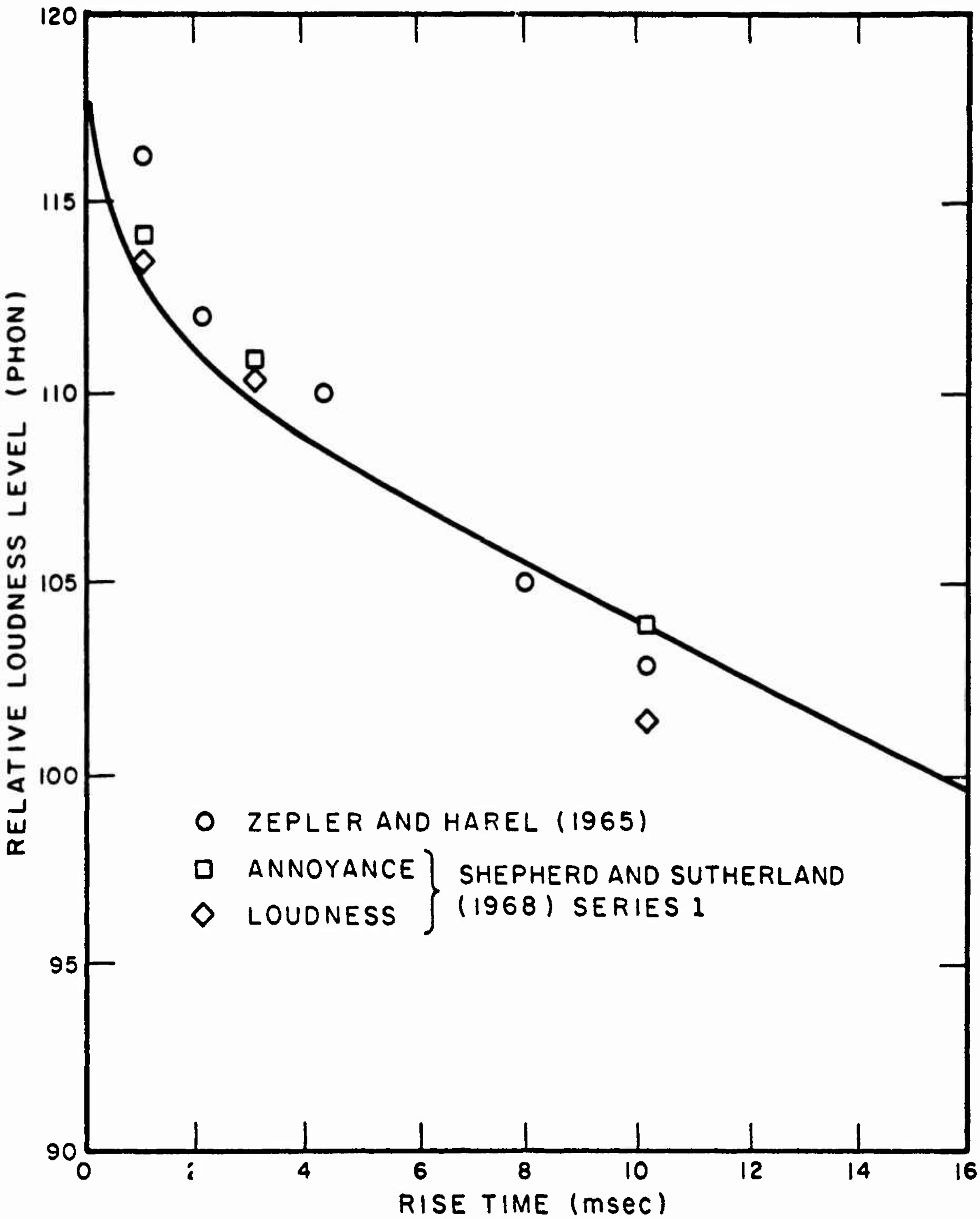

FIG.3 EFFECT OF RISE TIME OF N WAVE ON PREDICTED PERCEIVED MAGNITUDE (Data Points Represent Psychoacoustic Judgments from Two Studies)

boom to come from listening outdoors, then we might develop various *ad hoc* methods for measuring the magnitude of this particular acoustic transient. Even considering the effects of delayed reflection, we could still develop a fairly simple, yet accurate, procedure for assessing the apparent magnitude of this comparatively simple geometric wave.

We must realize, however, that probably less than a majority of our experience with the N wave will come from outdoor listening. Indoors, the sonic boom produces no standard wave shape nor duration. The wave at the observer's ear is a result of the interaction between the outdoor N-like wave and its interaction with the house. Nor can this interaction be accurately mirrored by treating the house as a linear, time-invariant system. It is obvious that various nonlinearities of the house convert the massive low-frequency energy of the N wave into acoustic energy at frequency regions where the ear is especially sensitive. The rattle of windowpanes, of glasses in the cupboard, or of pictures on the wall are examples of this secondary acoustic excitation. Thus, it is especially important to emphasize that a general procedure for predicting the apparent magnitude of transient signals should be developed; this general procedure should not be specialized to the N wave or to impulses having spectra like those in Fig. 1.

Ultimately, we will probably need to have a survey or estimate of the average sound levels we may expect to encounter in an average dwelling when that dwelling is excited by a sonic boom. To make this survey or estimate in a realistic and useful manner, we need to know the quantities that are important in assessing the apparent magnitude of impulsive sounds.

Apparent Magnitude of the Indoor Boom

Several investigators have attempted to compare the sonic boom, as heard indoors and out, with conventional jet noise (Pearsons and Kryter, 1964; Johnson and Robinson, 1967; Kryter, 1969). The available results raise several puzzling questions.

First, it is not completely clear how to account for the difference in annoyance judgments between indoor and outdoor listening for conventional jet aircraft. For such aircraft, an average house provides about 20-dB attenuation (Bishop, 1966). If one believes that the annoyance judgment is a result of the total acoustic disturbance produced at the eardrum, then one would expect to find that a noise judged inside *but measured outside* would be 20 dB greater than a noise judged to be equally annoying outside. The results of tests with conventional aircraft do not confirm this result. Apparently, people have more stringent standards of annoyance indoors than outdoors, and the noise heard inside *but measured outside* is only about 5 dB greater than the noise heard outside and judged to be equally annoying.

Qualitatively similar results have been found in tests with laboratory simulations (Johnson and Robinson, 1967; Pearsons and Kryter, 1964) and with actual booms (Kryter, 1969). The houses used by Kryter provided an outdoor-indoor boom attenuation around 5 dB. (This is much less than the outdoor-indoor attenuation of jet noise, because the house is a relatively poor attenuator of the low-frequency components that predominate in the boom spectrum. In fact, the nonlinear excitation of windowpanes, doors, or bric-a-brac can create an indoor stimulus that is comparable to or even greater than the outdoor stimulus.) Unfortunately, the picture is not entirely consistent, because some of Kryter's results appear self-contradictory.

The indoor-outdoor problem is, therefore, complex not only for jet aircraft, but even more so for sonic booms. At this time we recommend that the boom problem be left in abeyance until a more adequate understanding of the jet aircraft noise situation has been obtained.

Discussion

Before outlining the several areas of research needing further investigation, let us briefly summarize the preceding review of the literature so that our conclusions drawn from this review will be both evident and explicit.

The major problem, as we see it, is to determine the value of the ear's time-constant so that steady-state sounds and impulses can be measured on similar scales. Unfortunately, the previous studies do not agree as to the value of this parameter, nor are there any clear suggestions as to the variable, or variables, responsible for these discrepancies. Faced with these uncertainties, we can do little but to study conditions that are as close as possible to those encountered in the realistic situation. We should, for example, use "annoyance" rather than "loudness" instructions and attempt to maintain all other actual conditions. Hopefully, some agreement will emerge, but, since there are no really good leads to the sources of the discrepancies, we must await some further insight.

For the N wave itself, this uncertainty about the value of the time-constant is probably not critically important. As the N wave increases in duration, only the power at very low frequencies (1 Hz) is affected; such power is probably of little importance in the calculation of loudness or annoyance. For the outdoor N wave, then, the problem seems to be largely a matter of rise time — in short, the exact spectral weight to be given the acoustic power in the 50- to 500-Hz region. Because the loudness or annoyance of the N wave, *per se*, will probably become important in relative comparisons of two or more airplane designs, the equal-annoyance contours should be studied with considerable care.

Finally, because of the massive low-frequency power present in a long-duration N wave, we urge that some investigations be undertaken to establish the role of joint vibration and acoustic stimulation. A pilot study should attempt to determine whether or not there is any increment in annoyance caused by pairing acoustic and vibratory stimulation. This information is especially important since in most structures the boom is sensed as both an auditory and a vibratory stimulus.

Recommended Research

Unit 1. The ear's time-constant

The objective of this research is to determine how the ear integrates energy for impulsive sounds and whether the rules for such integration depend on the particular frequency content of the impulse. Specifically, the unit should establish the trade between the intensity and duration of impulsive stimuli, adjusted for equal annoyance, for the range of durations between 1/100 of a second and 10 seconds. The impulse should be generated by filtering a noise waveform. Octave filters may be employed and should cover at least four regions in the range from 50 to 1000 Hz. If at least ten durations are measured in the range from 10 to 10,000 msec, then any differences in the time-intensity trade in the various frequency regions should be evident.

It is important to use "annoyance" rather than "loudness" instructions, since there have been some suggestions that the ear's time-constant may be somewhat different for the two sets of instructions. At least ten subjects should be used in the experiment, and all subjects should participate in the experiments at all the frequency regions.

The experiment should be conducted in free-field conditions. If some tests are conducted in an anechoic test chamber, additional tests must be conducted at the lower frequencies to insure that reflections from the wall at the low frequencies have not influenced the test results.

Unit 2. Effect of rise time

The purpose of the second research unit is to determine with reasonable accuracy both the equal-annoyance contours in the regions from 50 to 500 Hz and how energy present in these regions should be combined in calculating the total annoyance value. This region of the spectrum is especially important in determining the annoyance of an impulsive stimulus such as the sonic-boom N wave, since the rise time of the N wave causes a break in this region of the spectrum. The integration rules for this frequency region must also be established, since at least two calculation schemes have proposed different *ad hoc* procedures to deal with the acoustic energy present in this frequency range.

First, the unit should determine the equal-annoyance contours for brief impulses (100 msec or less) whose energy is largely concentrated within 1/3-octave bands in the range of 50 to 500 Hz. Second, it should determine how two or more such bands should be combined in predicting the annoyance produced when both bands are presented simultaneously.

At least eight bands in the range 50 to 500 Hz should be studied, and the combination of at least eight pairs of bands should be measured. Also, four sounds (produced by combining three bands) and two sounds (produced by combining five bands) should be studied. If an anechoic chamber is used, some additional studies should be conducted both to investigate the problems of reflections present at the low frequencies and to determine the probable effect of these reflections on the experimental results.

The population of at least 20 subjects should include some range with respect to age.

Unit 3. Effects of vibratory stimulation

This study should be modest and of a pilot nature. Basically, we want to establish whether there is any increment in annoyance judgments when mild vibratory sensations are added during the presentation of the acoustic impulse. Hence, we want to present impulsive sounds alone and in conjunction with mild vibratory stimuli. If a positive result occurs, a more elaborate study of the phenomena should be undertaken. This study is of considerable importance since the observer hearing the boom within most conventional structures is subject to both the auditory stimulus and some small vibratory stimulus. Because people are often worried that the sonic boom is causing property damage and because the magnitude of the boom must be judged from the motion of the structure as well as from the noise it produces, this unit should determine how the vibratory and auditory components interact.

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C. EFFECTS OF THE BOOM ON TASK PERFORMANCE

Human startle responses to sonic booms have both physiological and psychological components. Although the physiological component is often more obvious and more readily measurable, the psychological component may prove of greater consequence in the long run. Physiological responses to startle are generally of short duration and commonly diminish with increased exposure to similar startling sounds. Whether or not psychological responses to startle share a similar fate remains unclear. Such a variety of human endeavors are potentially affected by acoustic startle that a wide range of activities must be investigated before firm conclusions may be reached about the nature of human response to startling sonic booms.

Of the numerous psychological phenomena associated with acoustic startle, the one most amenable to laboratory investigation is task interference. Task interference, which is likely to have observable and readily interpreted manifestations, may be expected to yield direct behavioral measures. Such behavioral measures stand in contrast to other types of psychological measures such as measures of opinion and, for that matter, to physiological measures, both of which may or may not have behavioral consequences beyond themselves.

The importance of task-interference effects lies in their immediate and potentially costly consequences. Much is made anecdotally of the effects of sonic booms on a heart surgeon or a diamond cutter. Unfortunately, little is known in a precise or controlled manner about the actual effects of sonic booms on task performance.

Review

The recency of interest in phenomena of boom-induced task interference accounts in part for the meager literature in the field. Several British workers, notably Broadbent (1957) and his associates (Broadbent and Burns, 1965; Woodhead, 1959, 1964, 1969) have published accounts of the effects of loud bursts of noise on human performance. In Czechoslovakia, Vlasak (1969) has recently found substantial decrements in visual reaction time and sensorimotor coordination for periods up to one half minute following brief, intense stimulation. Lukas and Kryter (1968) are among the few American workers who have contributed to the literature on boom-induced task interference. Research in related fields (e.g., pejorative effects of steady-state noise on performance, physiological effects of intense noise, etc.) is much more prevalent. A recent review article by Cohen (1969) summarizes much of the work on the effects of steady-state and impulsive noise on performance. According to Cohen, intermittent or random noises seem more likely than continuous noises to disrupt performance.

Most published studies of boom-induced task interference (e.g., Woodhead, 1969) attempt to demonstrate an immediate decrement in a single performance measure associated with an intense, aperiodic, acoustic signal. Glass *et al.* (1969) are among the first investigators to consider long term effects of noise on performance. Among the parameters of acoustic startle that have been studied are intensity (Woodhead, 1959), spectral composition (Lukas and Kryter, 1968), frequency, i.e., temporal density (Glass *et al.*, 1969), and expectedness (Glass *et al.*, 1969). Among the tasks employed have been proofreading (Glass *et al.*, 1969), problem solving (Glass *et al.*, 1969), mental arithmetic (Woodhead, 1964), manual tracking (Lukas and Kryter, 1968), and visual identification (Woodhead, 1959, 1969). Predictably, the most common findings have been that intense, unexpected signals interfere with complex task performance more than weak, expected signals interfere with simple task performance; however, we find little consistency in findings of either habituation or sensitization of task interference. For example, Lukas and Kryter (1968) found evidence for improvement in one performance measure and deterioration in another measure of the same task during four days of exposure to simulated sonic booms. Some of the inconsistencies in findings may be attributable to individual differences among observers, as noted by Plutchik (1959) in an early review article.

Broadbent and his associates believe that performance decrements caused by sonic booms are attributable to simple distraction of attention. Thus, performance decrements immediately following startle are interpreted as the consequence of disruption of concentration on task performance. If this hypothesis is accepted, there would be little reason to anticipate prolonged or increasingly severe task interference as a function of repeated exposure to sonic boom.

On the other hand, boom-induced task interference may be attributed to processes other than superficial distraction of attention. One such process might be disablement of function in the presence of emotional reactions such as fear or frustration that follow intense, unexpected stimulation. Chronic task interference of a cumulative nature could well result from such complex processes. The existence of task interference at long intervals after startle would argue against the Broadbent hypothesis. That position would also be weakened, if acoustic startle interfered with a well-practiced task that demands little or no attention.

Recommended Research

Three major goals of a comprehensive program of research on boom-induced task interference are:

1. Identification of the range of tasks susceptible to interference from sonic booms;

2. Evaluation of the nature and severity of interference as related to startle magnitude; and

3. Clarification of the short- and long-term time courses of boom-induced task interference.

These three equally important goals are discussed in order below.

Identifying the Range of Susceptible Tasks

Clearly, not all behaviors suffer equally from boom-induced task interference. Simple tasks that do not tax human capacities, such as those requiring only infrequent attention or those that are well practiced, should be less prone to interference than their complementary tasks. The exact correspondence between actual tasks and the generalities mentioned above remain to be discovered. For example, are behaviors involving sensorimotor coordination more sensitive to boom-induced interference than tasks that require only cognitive or only motor involvement? Is the acquisition of a skill more likely to suffer from boom-induced interferences than the practice of the same skill? Research tasks should be selected with the aim of specifying relative sensitivities of different categories of behaviors to boom-induced interference. Of great value would be a contrast between behaviors that remain consistently immune to interference from even the most startling stimuli for long periods of time and behaviors that suffer severely and increasingly from even the slightest startles.

Researchers interested in this study should suggest tasks that sample a wide range of human behaviors. If, during the progress of the research effort, specific behaviors are identified as particularly susceptible to interference from sonic booms, investigations of similar behaviors would obviously be in order.

Evaluating Interference as a Function of Stimulus (or Startle) Magnitude

Dosage relationships must be assessed within each category of behavior. Both the intensity and temporal density of startling signals must be systematically explored over a range of at least one order of magnitude. Identical schedules of startle intensity and frequency should be administered in all experimental evaluations of task sensitivity to boom-induced interference.

Another important dimension of startle is "expectedness" or predictability. Although a laboratory is a difficult setting in which to produce a totally unexpected signal (even by deception of the subject), manipulating the regularity of startle occurrences is very important.

Since dosage information of the sort discussed above is crucial for the design of experimentation, effort in the early stages of the research program must be expended in acquiring such information.

Clarifying Short- and Long-Term Time Courses

Latency of onset of boom-induced task interference is generally assumed to be in the hundreds of milliseconds; yet, startle might well interfere with the performance of some tasks seconds or tens of seconds after its occurrence. The experimental conditions should provide opportunity for potential delayed effects to manifest themselves, and data should be carefully analyzed to test for the existence of such effects.

Evaluating the longer-term or cumulative effects of repeated exposure to startle is also an important consideration. Either habituation (decreasing sensitivity) or sensitization (increasing sensitivity) to repeated startles, or neither, may occur under different task-specific conditions.

Criteria for Selection of Tasks, Measures, Stimuli, and Subjects

Task interference may be direct or indirect. Direct forms of task interference may demand responses that actively compete with task-relevant actions. Indirect forms of interference may merely inhibit or impede task performance. For both direct and indirect forms of interference to be measurable, tasks selected for experimental examination should permit several types of errors of omission and/or commission. Ideally, tasks should be of such a nature that minor changes in experimental procedure provide an opportunity for alternative forms of interference to occur.

Since the time course of boom-induced performance decrements is of considerable interest, a necessary condition for selection of measures of task interference is the availability of a dependent variable that yields a continuous record of ongoing activity before, during, and after the occurrence of a boom. Further, since different forms of task interference may exhibit differential effects on alternative measures of task performance, it is important that several dependent variables of different sorts be available.

Actual or "realistic sounding" simulated sonic booms need not be employed as the startling stimuli for the proposed research. Acoustic signals of intensities, rise times, durations, and spectral compositions reasonably similar to those of sonic booms would suffice. It is, however, important that the vibrational component of the indoor sonic boom be reproducible, so that the component's significance in task interference effects may be evaluated. It should be determined quickly whether the vibrational component of

the acoustic signal contributes to boom-induced task interference. If no significant effects of vibration are found, simulating the infra-audible portions of the sonic boom spectrum would not be necessary in further research.

We suggest that a minimum of twenty subjects be employed initially in all experimentation. If variability among subjects of particular ages or sex predominates over variability due to experimental manipulations, additional subjects would be required to obtain stable estimates of both task interference and individual differences. Should individual differences prove great, subjects may acceptably serve as their own controls; where possible baseline data with which the subjects' subsequent data may be compared should be established prior to exposure to startle.

Careful attention must be paid to subjects' motivation throughout all experimental conditions. The use of monetary rewards and/or fines is encouraged, if necessary to maintain performance at stable levels.

The following tasks may be considered for inclusion in a comprehensive program of research. Prospective researchers should develop additional or alternative tasks and measures. Key personnel in the administration of the research should have broad experience in the measurement of human performance.

Task 1. Eye-hand coordination. A series of related tasks requiring coordination of visual inputs and manual outputs is suggested as a means of evaluating boom-induced interference with sensorimotor coordination. The basic experimental apparatus should include a computer-driven CRT display and a joystick manipulandum. Such equipment permits creation of a broad range of sub-tasks, all of which yield multiple continuous measures of performance. Two classes of sub-tasks that might be employed are the following:

a. Visually guided pursuit: A small target is moved across the CRT face under computer control. The subject must keep the target enclosed within a small circle, the position of which is controlled by movement of the manipulandum. Variants of the basic task permit assessment of speed-accuracy and amplitude-accuracy tradeoffs. Possible performance measures include time on target, time while cursor figure is more than a fixed distance from the target, RMS error, etc.

b. Manual control based on visual feedback: The manipulandum and/or target should be driven by computer-generated classical waveforms such as step and ramp functions. The subject must maintain a target within established limits on the CRT by continuous adjustment of the manipulandum. Tasks of a wide range of complexity may be generated in such a situation, depending on the basis of the available feedback, the damping factors of the joystick,

and the geometric configuration of the limits of the visual display. Both gross and fine errors may be induced by boom-related interference. Performance measures should include latency of corrective movement, time within bounds, mean under- or over-correction, and so forth. One might also consider a low-stability task such that momentary lapses cause sizeable transients in overall system error and correspondingly long recovery times. A variable-stability task might permit establishing thresholds that can be traced over the duration of the experiment.

During performance of the above tasks, boom-like acoustic signals should be presented on schedules derived according to the criteria mentioned earlier. Special attention should be paid to the values of dependent variables not only immediately before and after the occurrence of startling signals, but also at longer intervals after startles. Boom-induced task interference, if found, should be studied during different phases of the subjects' performance of the tasks, i.e., during learning, practice, and highly skilled performance.

Participation of the subjects in each of the sub-tasks should be strongly motivated by monetary considerations. Fines should be imposed for errors in excess of established rates; rewards should be offered for performances exceeding the average. If habituation to boom-induced interference is found, the booms should be temporarily suspended, then resumed after some time period, so that potential recovery of startle responses may be explored.

A major portion of the proposed research may be conducted within the framework of the sensorimotor tasks suggested above. However, bidders should also consider investigation of alternative behaviors, including perhaps those described briefly below. If bidders ascribe considerable importance to such alternative tasks, a systematic research program based upon those tasks might be developed.

Task 2. Cognitive behavior. The purpose here is to study effects of startle upon a purely cognitive task, one which requires no motor coordination. The subjects' task might be to perform arithmetic operations upon random numbers without the aid of pencil and paper. The complexity of this task depends on the size and range of the numbers, the nature and variety of the operations, etc. Previous research has already demonstrated differential effects of startle on different aspects of mental arithmetic.

Discrete, but frequent, measures of errors of omission and commission may be provided by the subjects' solutions to the problems. The time required to solve the problems may also be affected by startle.

Task 3. Motor behavior. To test the hypothesis that boom-induced task interference is the mere disruption of attention requires a task that demands the performance only of rote, mechanical actions entailing little or no cognitive involvement. If acoustic startle interferes with performance of such a task, it would be difficult to attribute the interference to simple disruption of attention.

One appropriate task might be repetitive movement of the manipulandum of Task 1 according to a preset pattern of starting, stopping, and moving to different locations in serial order. Timing and sequential errors are readily measured in such a task.

Another appropriate task might be assembly of identical but complex small mechanical parts. A simple assembly plan, which once understood requires minimal concentration or other mental effort, should insure that the task is one of primarily manual dexterity. Subjects should be paid for the number of assemblies completed in a fixed time period. Simple measures of boom-induced task interference would include the difference in assembly times for single units in the presence and absence of startle, and the total number of units assembled shortly before and shortly after the occurrence of a startling signal.

Task 4. Short-term memory. If, in fact, acoustic startle interferes more with learning than with skilled performance, then specific aspects of the learning process should be examined. One aspect of learning that might prove highly sensitive to boom-induced interference is short-term memory.

Attributes of short-term memory that could be impaired by startle include speed, capacity, and accuracy. The rate at which information may be read into or out of short-term memory may be measured with tachistoscopic display apparatus. Displays should be presented briefly at well-defined observation intervals that may or may not be in close temporal coincidence with startling signals. Measures of short-term memory impairment in such situations would include increases in intensity and/or exposure duration of displays needed to support a fixed accuracy of recall, amount of correctly recalled information, and latency of response.

Another simple task that could provide insight into the nature of boom-induced interference with short-term memory is a digit-span task, in which a subject is required to repeat strings of numbers of varying lengths after varying delay periods.

Task 5. Perceptual decision making. Acoustic startle may interfere with task performance not only by disturbing the processing of information (as is implicitly assumed in many discussions), but also by impeding the acquisition of environmental information. A signal-detection task would permit independent assessment of sensory and non-sensory components of information processing.

A one-interval (yes-no) visual detection task could provide information about the effects of acoustic startle on both perceptual sensitivity and response factors. Startle could well influence one, but not the other. It seems plausible, for example, that a human observer might utilize identical sensory information more conservatively in the presence of startling signals than in their absence. If such were the case, false-alarm and hit rates in comparable blocks of trials under conditions of startle and non-startle would provide indices of the effects of booms on the two components of perceptual decision making.

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III. SOCIOLOGY

The areas of research discussed in the previous sections of this report deal with potential effects of the boom on individuals. This section also deals with effects on individuals, but it treats individuals as members of society. Additionally, this section deals with the effects of the boom on society itself, and, reciprocally, with the effects of society on the boom. This section thus shares the concern with individual welfare that is central to other sections of the report, but it adds a concern for "the common weal."

We preface our recommendations for research projects with a description of a social-effects model so that we may establish the several areas of concern and clarify the relationship among the projects.

A. A SOCIAL-EFFECTS MODEL OF THE SONIC BOOM

Once an individual verbalizes his response to a phenomenon, that phenomenon acquires social meaning. The sonic boom is particularly fraught with social meaning because, to the individual, the larger society controls the boom and hence inflicts it upon him; it is to the larger society, therefore, that he directs his efforts at abatement.

This makes society the focal point of our model. As used here, the term has a strong connotation of nation and, thus, of the centrality of government. Society is the social order from which an individual derives his identity as an American; yet, at the same time, it is the ubiquitous "they". Discussed in such a connotative manner, society remains a fluid concept. To the individual, however, the term is very real in the sense that people do relate to one another at the level of a total society; that this relationship gives them a sense of identity; that society often seems external to them; and that, while constraining them, it gives them freedom. The aspect of this "total American society" that is most salient to our present considerations is the institution of air transport.

In Fig. 4 (a flow diagram of the social-effects model), the sonic boom is represented as a product of society because, although only a segment of society produces the boom, the "total society" is deemed responsible. The boom is a stimulus invested with meaning derived from its social origins. To the degree that this meaning is evaluative, it determines the attitudes of individuals towards the boom. These attitudes, in turn, may result in one of several kinds of individual activity. Negative attitudes result in complaints, which may be communicated to a number of different recipients: family, friends, or acquaintances; complaints may be propagated through news media via letters to the editor or may take the form of direct solicitations or demands for abatement by

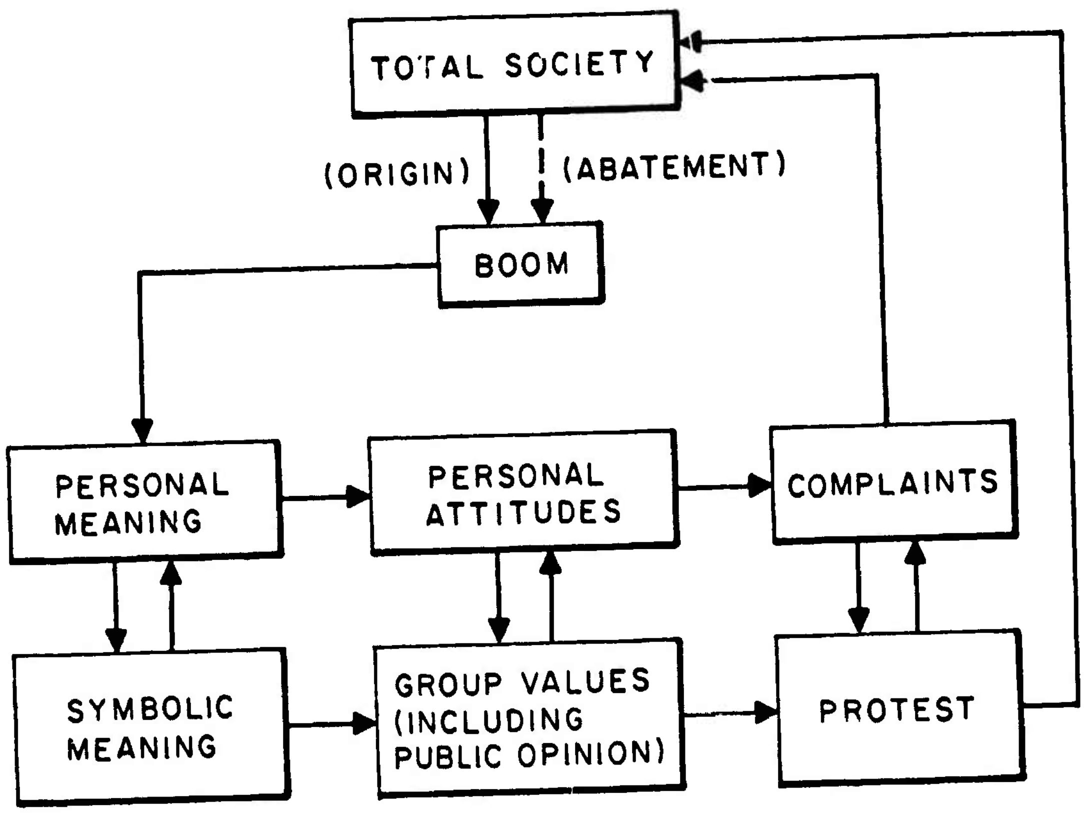

FIG.4 A SOCIAL-EFFECTS MODEL OF THE SONIC BOOM

complaints to administrative, executive, and legislative officers or agencies or by initiation of judicial or legislative processes. Our model interprets an attempt at abatement as a communication directed at the society that permits the sonic boom.

Thus we come full circle: The society that controls the boom creates a stimulus; the boom stimulus has meaning for individuals; meaning develops attitudes; attitudes can give rise to complaint action; such action demands a policy change from society. In summary, the sequence is society-boom-meaning-attitudes-complaints-society.

This sequence, which constitutes the "individual" cycle, has several salient features. First, the cycylical action is strongly conditioned by individual differences in the areas of meaning, attitudes, and complaints (including legal representations made both to legislative and to judicial agencies). Second, progression from one step to the next is problematical: the stimulus does not necessarily have meaning for all; meaning does not necessarily beget an attitude; nor does an attitude necessarily beget a complaint; nor do all complaints necessarily result in abatement. Third, we assume a feedback loop between society on the one hand and complaint activity on the other. If the social structure includes complaint mechanisms, we assume complaints will be more numerous; if complaints have a high probability of influencing abatement, we again assume a higher rate of complaints. Thus, the cycle is influenced by two social characteristics: how society receives abatement communications and how it uses them in formulating policy decisions.

As shown in Fig. 4, for each of the individual stages between the boom stimulus and the society, there is at least one corresponding "group" stage: private meanings become symbolized through being exchanged — both in private and in the mass media — and through being shared; in this fashion meanings become public opinion. We might expect, therefore, that the greater the exposure to sonic booms, the greater and more intense will be public opinion and that meanings may become stereotyped; that is, the boom stimulus may come to have a common, emotionally anchored meaning that over-simplifies the situation. Similarly, the process of forming public opinion produces group evaluations of various objects of public concern. These evaluations, which are the social correlates of attitudes, take the form of judgments that objects are either good or bad and, like symbolic meanings, such judgments may also become stereotyped. Finally, we must consider the other salient feature of the cycle, that of the organized protests, petitions, lobbies, and lawsuits that are group counterparts of complaints at the individual level.

The relationships between group and individual phenomena are more complex than we can describe here. However, each member of the correlate-pair reinforces the other. Symbolic meanings are

initially compounded of private meanings, but private meanings are more readily formed when shared symbolic meanings are available as models. In similar fashion individual attitudes are related to group values and private complaints are related to group pressures for abatement. In each case of individual and corresponding group phenomena reinforcing one another, the processes are mediated in a social situation by the communication of fact, opinion, values, intentions, and by action.

We include these group phenomena in the model so that we may trace the cycle by different paths (Fig. 4). Beginning again with society as the source of the boom, we still have the boom as a stimulus for individuals, but this time the meaning, viewed here as symbolic rather than private, expresses shared social values to which people respond by group action seeking abatement for an entire community. Again, the total society responds in some fashion consonant with its central structure, its dominant values, and its procedures for reconciling conflicting interests. A third cycle might include a combination of individual and social antecedents; for example, an individual complaint can be motivated by group values based upon completely shared meanings.

The problem of setting boom criteria requires information that is additional to the social-effects model outlined above. Part of this information can be gleaned from a well-recognized social pattern that relates the intensity of noise to community reaction. Within this pattern, community reaction to low noise levels tends to remain minimal as noise increases; however, at a certain point, the intensity (or extensity) of community reaction begins to vary directly with the increase in noise levels, until another point where the reaction levels off and the increases in noise levels no longer provoke increases in public reaction. The pattern assumes a considerable variance in these relations and accounts for this variance in terms of those community differences that are traceable to non-noise factors (Stevens *et al.*, 1955). This pattern, when adapted to noise around military air bases, was used to measure reaction in terms of whether complaints are individual or group in character (Stevens and Pietrasana, 1957).

A number of the elements in our model can be related to boom intensities in terms of this community-noise pattern. Taking a percentage of persons in a boom-exposed area as our metric, we can show how annoyance (an attitudinal reaction), the extent of adverse public opinion, the concentration of individual complaints, and the participants in group protest are related to boom intensity. This relationship is shown symbolically in Fig. 5 as a set of S-shaped functions. Not all curves are of the same height. At low noise levels, more people would be privately annoyed than would consciously share negative values relative to the boom or its sources. We know from empirical studies that complainers represent only a small proportion of those annoyed (Borsky, 1965; Tracor, 1969). We also assume that at low boom levels individual complainers would outnumber those involved in group protests.

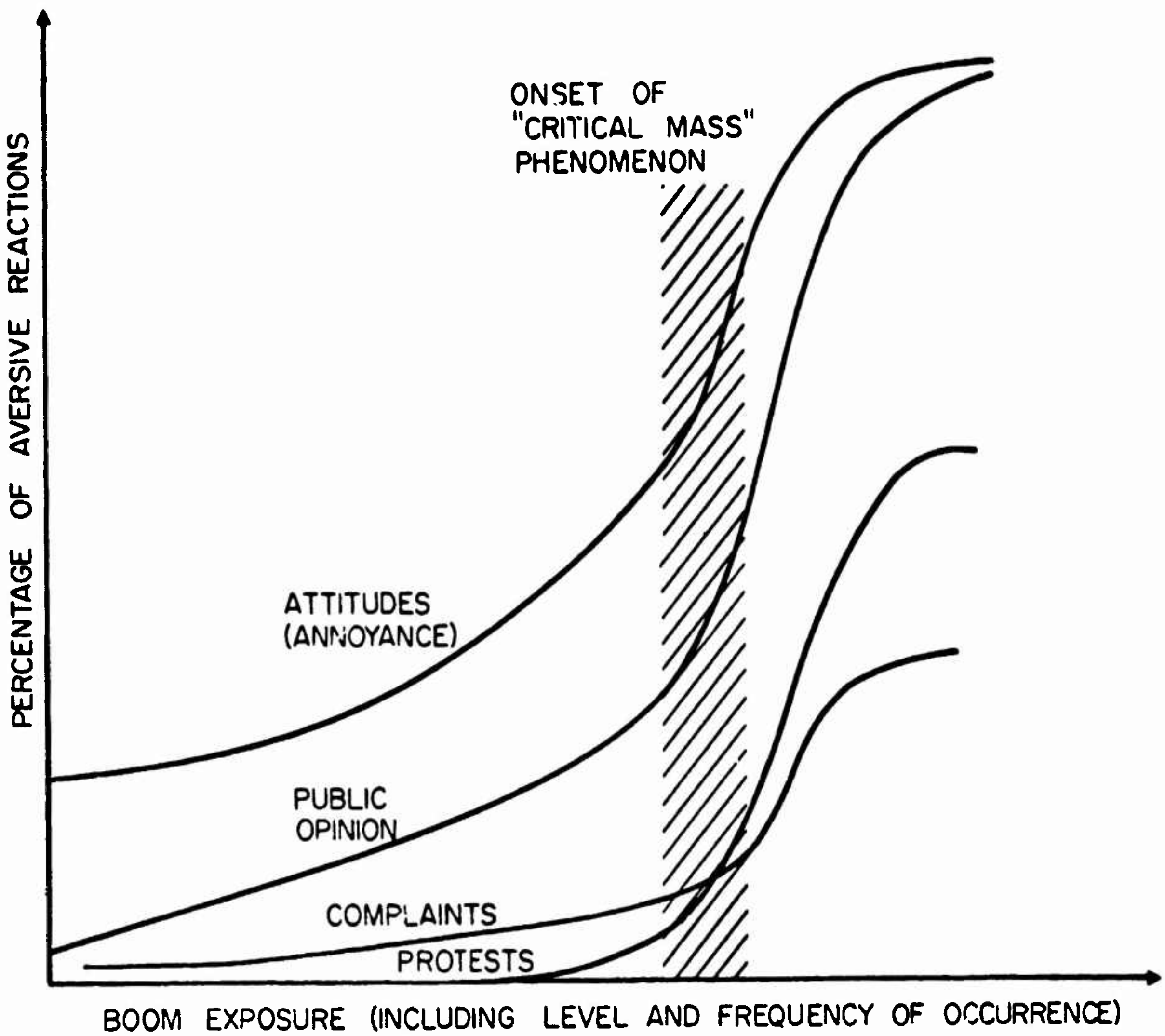

FIG.5 POSTULATED RELATIONSHIPS BETWEEN AVERSIVE REACTIONS AND BOOM EXPOSURE

However, as boom intensities rise we expect interactions among these elements. As annoyed individuals become more numerous in the population, their communication would result in the coalescence of shared negative values. Such sharing would, in turn, create an atmosphere of reinforcement for complainant activities. Without strong environmental restraints, participation in organized complaints would escalate rapidly; this escalation would foster more widespread annoyance because of the new meaning with which organized complaint activity would invest the boom itself. The phenomenon, seen as a rapid increase in the slopes of the curves in Fig. 5, is one of "critical mass".

This further development of the model permits us to isolate four important areas of concern for research. All four areas are crucially related to the "critical mass" phenomenon, and each is developed more fully later in this section of the report. Here, we merely attempt to demonstrate their relevance.

(1) The first area focuses on the individual with regard to *meaning, attitudes, and individual differences.* The Oklahoma City survey data clearly demonstrate the correlation between meaning and annoyance (Borsky, 1965). These three factors comprehend the symbolically mediated, subjective responses to the boom and provide both the basis for group evaluations and the motivation for abatement activity (group and individual). Individual differences are a crucial issue, since they underlie the relation between the percentage of people annoyed and noise intensity.

(2) The second area concerns the *conditions that convert attitudes into action.* Action is more effective than are subjective attitudes in influencing social policy; furthermore, action is more compelling than are symbols in "recruiting" individuals to a point of view.

(3) The third area concerns the *conditions that translate individual phenomena into group phenomena.* The critical mass is formed in two crucial steps: the conversion of individual attitudes into group values and the displacement of individual complaints by group action.

(4) The fourth area concerns the *effect of boom intensity on society itself.* Any organization, society included, performs two principal functions: one is to fulfill the purpose for which the organization was formed, and the other is to maintain itself. Our society, in fulfilling its purpose, is often called upon to perform imcompatible functions and yet maintain its integrity while doing so. We expect society to furnish transportation to its members and, at the same time, to protect our environments against noxious intrusions. There is, of course, a possible incompatibility of these two functions where the SST is concerned. And, failure to avoid or resolve this possible incompatibility could very well weaken the structure of society itself. For example, if great pressures

develop for abatement of the boom, but are contained without affecting boom levels, these pressures may turn against the social structure. This diversion may take such active forms as reform or revolt or such passive forms as withdrawal and alienation.

Review

We review here past studies of the social effects of sonic booms and relate their results to the model described in the foregoing. An effort is made to relate social effects to boom exposure (in terms either of levels or frequency) wherever the data permit. First, we briefly describe the major American field studies, but we also draw upon the findings of British and French studies. None of the latter are as extensive as the American studies we describe. Next we review the findings in these studies that bear upon attitudes, complaints, and group activity – the three chief elements of the model just described. We then make brief mention of alienation, an element missing in these studies, but one for which we later propose a research program. We conclude by examining past findings on adaptation and accommodation.

The first extensive study to be made in this country was at St. Louis, Missouri, in 1961 and 1962. The program spanned more than six months, during which there were 76 sporadically scheduled overflights, from two to six per day (with gaps, one nearly a month long), developing nominal overpressures of from 0.8 to 3.1 psf. The planes flew a predetermined track with a lateral error of less than 1-1/4 miles. The survey assessed attitudes that conditioned annoyance with sonic booms and interference, annoyance, and complaints that were direct effects of the booms (Nixon and Hubbard, 1965).

In 1965, the Oklahoma City study was scheduled as a follow-on to the St. Louis study. The flight program lasted six months during which there were eight regularly scheduled daytime overflights daily. Nominal overpressures increased from 1.13 psf at the beginning of the program to 1.6 psf at the end. The survey issues were highly similar to those investigated at St. Louis, but they were much better conceptualized and operationalized (Borsky, 1965). Three sets of measures were taken: the first by face-to-face interview, the second and third by telephone. The Oklahoma City survey is so far the best planned, most extensive, and most informative survey of reactions to the sonic boom.

The field experiment at Edwards Air Force Base was conducted in 1966. It included paired-comparison tests of jet noise and booms from supersonic aircraft. Edwards Air Force Base regularly experiences four to eight daily booms of 1.2 psf. During the one-month experiment, flights averaged between 9 and 10 per day at an average overpressure of 1.7 psf. The major study used both residents of Edwards Air Force Base and residents from the nearby communities of Redlands and Fontana, California, in paired-comparison

tests of subsonic and supersonic jets, indoors and outdoors. A sample of Edwards residents were also given an attitude test (Sonic boom...Edwards, 1967).

In 1967 and 1968 a multi-city study surveyed residents of Atlanta, Dallas, Fort Worth, Denver, and Los Angeles. These cities were overflown for a period of between four and five months; the average frequency of overflights varied from less than once a month to three per week. Average boom pressures varied from one city to another, between 0.95 and 1.81 psf. This study particularly clarifies the nature and concerns of complainants. As yet only tentative reports of the multi-city study are available (Tracor, 1969).

Attitudes

In our recommendations for research, we treat attitudes as complex concepts by which people can handle and order objects, situations, and ideas. One component of the sonic-boom attitude is cognitive: it consists of beliefs about the sonic boom and about its origins. Borksy (1965) shows wide variations in reactions to the boom that are traceable to favorable or unfavorable beliefs concerning it. (The specific beliefs are dealt with in detail in Sec. E.) This effect of beliefs on reactions to boom was also noted in the St. Louis study, and measurements of beliefs and analysis of their effects were refined in the Oklahoma City study. The two strongest belief complexes relate to the importance and inevitability of the SST, on the one hand, and the beliefs concerning its effects, particularly on property, on the other. A French study finds a close association between reactions to the boom and belief about whether the SST ought to be developed (deBrisson, 1966). The multi-city study confirms a close association between reactions to booms and orientations to property.

The second and central component of an attitude is effective and evaluative. Since few people have been found with positive feelings towards the sonic boom, this component is generally measured by evaluating annoyance. The operations for measuring annoyance vary widely.

In the St. Louis study, annoyance was measured purely as a function of some prior disturbance. This procedure follows the concept of annoyance, as an effect of activity interference, that had previously been employed in studies of subsonic jet-aircraft noise. The order of disturbing events in St. Louis was (1) house rattle; (2) startle; and interference with (3) sleep, (4) rest, (5) conversation, and (6) radio or TV listening. The range of disturbance was from 93 percent for house rattle to 14 percent for radio or TV listening. Fewer people were "annoyed" than were "disturbed" (ranging from 54 to 6 percent), although the order remains the same. This same order of disturbing events held for Oklahoma City, although, except for house rattle, percentages were lower in Oklahoma City. Flights in the Oklahoma City survey, although more

numerous, occurred only during daylight hours. Annoyance patterns from these disturbances were almost identical in the two cities.

The Oklahoma City study allows us to estimate the effect of boom intensity on disturbance. Reactions were categorized as to whether respondents lived from 0–8, 9–12, or 13–16 miles from the ground track. At the end of the study, nominal boom overpressures averaged 1.6, 1.4, and 1.0 psf, respectively, for the three zones. Considering the extreme values, except for house rattle (for which the respective percentages are 95 and 79), the percentage of persons whose activities were disturbed at the 1.6-psf level was approximately double those disturbed at the 1.0-psf level.

A French survey showed that in the Strasbourg and Bordeaux areas, which are overflown regularly by supersonic military planes, about 26 percent of the respondents were disturbed by the boom in their daily activities. This figure does not include startle and house rattle (deBrisson, 1966). In the multi-city study, disturbance rates seem to be somewhere between those found for St. Louis and Oklahoma City, although the data-gathering categories were different. In the multi-city study, there is no way to compare disturbance by boom level or boom frequency. In neither the French nor the multi-city study was disturbance directly related to annoyance.

Although the St. Louis study reported annoyance solely as a measure of disturbing events, many subsequent studies reported annoyance with the sonic boom *per se*. In Oklahoma City those annoyed increased over time from 37 to 56%. At the end of the study, 58% of those exposed to a boom level of 1.6 psf were "more than a little annoyed," while 38% exposed at the 1.0 psf level were annoyed to a similar degree. Forty-four percent of those with favorable beliefs and 68% of those with unfavorable beliefs were annoyed at the study's end.

In the French study, 83% of the people are reported as "disturbed" by the booms. Since the disturbance was not tied to any specific event, we take it to be a direct measure of boom-induced annoyance.

In the multi-city study, 60% of the respondents were in the two highest categories of annoyance at the end of the overflight programs. Since annoyance was measured differently in the terminal survey from in the preliminary survey, no increase in annoyance can be ascertained, nor, as mentioned above, can one assess differences due to variations in boom exposure. However, the multi-city study examined the thesis that sonic-boom annoyance, like jet-aircraft-noise annoyance, is triggered by activity interference. The statistical analysis used suggests strongly that annoyance precedes rather than follows any interference with activities (Tracor, 1969).

The third component of the attitude concept is conative, a tendency to act. In sonic boom and similar research, this component is sometimes operationalized in terms of a desire to complain. The

desire to complain has been dealt with thoroughly only in the Oklahoma City study. Like annoyance, it was found to vary with time of exposure, belief patterns, and boom intensity. In general, about half of those who were seriously annoyed by the boom wanted to complain about it. Rates of annoyance in all studies and the desire to complain in the Oklahoma City study were good predictors of complaint action.

Complaints

We review here three types of findings concerning sonic-boom complaints: complaint rates, nature of complaints, and characteristics of complainers. There were about 17 complaints per 100,000 population in the multi-city study, about 1000 per 100,000 in the St. Louis study, and about 5000 per 100,000 in the Oklahoma City study. Although these rates vary with boom exposure and other environmental factors, they also may vary with the procedures available for complaints. For example, to call the St. Louis complaint center, one had to make a toll call into a very busy air-base switchboard (Nixon and Hubbard, 1965).

The sonic-boom complaints that are filed, unlike most subsonic jet noise complaints, usually involve property damage, or a fear of property damage so that the logical outcome of most sonic-boom complaints is a claim for damages (Borsky, 1965; Nixon and Hubbard, 1965; Tracor, 1969). Indeed, one of the characteristics that distinguishes complainants from non-complainants (and annoyed from non-annoyed) is concern with property. Belief that sonic booms damaged property was measurably greater for complainants in St. Louis and Oklahoma City; the data of the multi-city study showed that more complainants than non-complainants owned their homes, owned more expensive homes, and more strongly associated booms with property damage.

All three studies related complaints to degree of exposure and of annoyance. Beliefs that the SST is necessary and that the boom cannot be reduced were found both in St. Louis and Oklahoma City. In St. Louis, complaining was found to be associated with the extent to which the respondent's community was organized for action and his exposure to subsonic jet noise. In the multi-city study, socio-economic status, the frequency with which the respondent discussed the boom with others, and the definiteness of his opinions concerning it were found to be correlates of complaining.

Group phenomena

Few data have been reported concerning group protests to sonic booms. The Oklahoma City program apparently stimulated an anti-boom movement. Borsky (1965) mentioned that in the latter months of the study organizations were urging individuals to complain, and Nixon, in a recent review of the study, noted that the Oklahoma City Council voted to recommend discontinuing the program.

Nixon (1969) also mentioned organized efforts to encourage complaints as well as counter efforts to strengthen acceptance of the program and to discourage complaints. We have no data on the conditions surrounding this group action, although we have not reviewed existing news reports of it.

Alienation

So far we have reviewed the findings of past studies that bear on the three major elements of our model: attitudes, complaints, and group phenomena. In the following, we recommend research on possible effects of booms on the social order if abatement does not take place. The latter research program focuses on the phenomenon of alienation. Neither alienation, nor any other line of inquiry concerning the effects of unabated sonic booms on the well-being of society, has been explored in previous studies.

Adaptation

In several past studies the data were examined *post hoc* for evidence of "adaptation", that is, for an attenuation of reactons to booms over time. The Edwards and the French studies both looked at the phenomenon directly. A number of studies (including these two) also examined "accommodation", that is, willingness to tolerate booms. These two concepts are not explicitly captured by our model. Actually, we share the high value placed by earlier investigators on the concept of adaptation, although, for reasons presented in the next section, we are less enthusiastic about the usefulness of the concept of accommodation, at least as currently measured. First, we describe three analyses of adaptation; then we relate the findings of the French study and of the study at Edwards Air Base.

St. Louis survey data were gathered at one point in time. After the close of the official overflight program, about an equal number of overflights (74) were made in three months, some of which may have produced high-level booms. The complaint rate climbed rapidly; the investigators cite others who speculate that the increased complaints were due to accumulated annoyance as well as to unusually intense booms (Nixon and Hubbard, 1965). This finding implies that, in St. Louis, adaptation may have been low.

Annoyance steadily increased over the three successive measurements that were made in the Oklahoma City study; so did boom levels. An analysis held boom levels constant over time by measuring areas that were increasingly distant from the ground track on each succeeding measurement. This analysis indicated that the rate of annoyance did not change with time (Borksy, 1965).

The multi-city study was based on a schedule of less than one overflight every two days; the measurement program did not lend itself to a clean test of adaptation phenomena. On the basis of

gleanings from the data, the authors concluded that adaptation (in terms of psychological adjustment) did take place, but that accommodation did not change (Tracor, 1969).

A direct measurement of adaptation was included in the French survey. Sixty-three percent of the respondents replied affirmatively to the question, "Would you say the bangs startle you just as much every time?" (deBrisson, 1966).

The study at Edwards Air Force Base attacked the problem of adaptation in several ways. On a mail questionnaire, 60 percent of those living at Edwards Air Force Base felt that the sonic boom had become "more acceptable" by reason of their being regularly exposed to it. With age held constant, the length of respondents' residence on the air base related positively to their acceptance of the boom. Base residents and residents from nearby civilian communities who had heard no sonic booms and few low-flying jets were given paired-comparison tests of actual flyovers in which they were asked to equate the acceptability of sonic booms and noise from low-flying jets. Heard outdoors, sonic booms of 1.7 psf were equal in acceptability to jet noise of 105 PNdB for Edwards residents and to jet noises of 107 and 109 PNdB, respectively, for the two civilian communities. Indoors, these sounds (measured outdoors) were equated at 109 PNdB for 1.7 psf by Edwards residents and at 118 and 119 PNdB for the two civilian communities. In assessing the data, there is good reason to suspect prior adaptation at the Air Base to both sonic booms and subsonic jet noise; hence the latter may not have been an equal standard of comparison for the airbase and civilian communities. However, the questionnaire data do indicate a random relation between the acceptability of subsonic jet noise and the length of residence on the base; on the other hand, they show the positive relation described above for sonic booms. Unlike the St. Louis and Oklahoma City studies and contrary to the findings of the French and multi-city study, the Edwards study produced a preponderance of evidence to support adaptation, at least on the part of military-connected personnel (Sonic boom...Edwards, 1967).

Accommodation

Closely related to the issue of adaptation is the issue of accommodation, which has been operationalized by asking respondents about the "acceptability" of the boom or, more simply, whether they "could live with" a specified boom environment. This variable had been extensively used in past research, but we hesitated to develop it either in the model outlined above or in the research that follows, despite the fact that results using the variable have been replicated in several studies. Our hesitancy arises from a fear that the variable is a false friend, that it promises to predict behavior that it cannot predict. If people say today that they cannot accept or cannot live with an experimental noise situation, what will they do if tomorrow it becomes a reality?

The accommodation variable is not found in the reports of the St. Louis study, but it occupied a central place in the Oklahoma City analysis. The percentage of respondents who felt that they could learn to live indefinitely with eight booms a day decreased from 91 percent early in the survey to 73 percent at the end. At the end of the study, 71 percent at median nominal overpressures of 1.6 psf, 75 percent at median nominal overpressures of 1.4 psf, and 86 percent at median nominal overpressures of 1.0 psf, felt they could live indefinitely with eight booms a day. Overall at the end, 91 percent of those who had most favorable beliefs about SSTs, but only 57 percent with the least favorable beliefs, predicted they could live with eight booms per day (Borksy, 1965).

In the Edwards study 14 percent of the residents regarded their normal 4 to 8 daily booms at 1.2 psf as unacceptable; this percentage increased to 26 for the ten daily booms at a nominal 1.7 psf that characterized the period of the study. These survey results coincide with data gathered under controlled experimental conditions: 27 percent of the experimental subjects at Edwards found booms of 1.7 psf unacceptable indoors. Forty percent of the inexperienced civilian-community subjects judged booms to be unacceptable under the same circumstances. Booms of the same levels heard outdoors were judged unacceptable by 33 percent of the Edwards and 39 percent of the civilian-community subjects (Sonic boom...Edwards, 1967).

The multi-city study did not directly measure accommodation. In the French study, 62 percent of the respondents felt that they either could not tolerate ten booms per day at all or only "with great difficulty."

In "Operation Crackerjack", a small British experiment using both planes and explosives, subjects listening indoors were aware of, but not bothered by, booms of less than 0.5 psf; judgments of booms of 2.2 psf ranged from tolerable to objectionable, whereas booms at 2.5 psf were consistently judged to be objectionable (Warren, 1961).

Recommended Research Areas

We recommend research on the social and social-psychological effects of the boom in these five areas:

1. Meaning, attitudes, and individual differences with regard to sonic booms.
2. Factors that facilitate and inhibit individual complaints about sonic booms.
3. Factors that facilitate and inhibit the conversion of individual attitudes and complaints into public opinion and community protest.
4. Conditions under which sonic booms might weaken the social structure.

5. Historical reconstructions of the effects on humans of supersonic flights and of the formulation of restrictions on military supersonic flights.

The contents of the first three areas of research are derived directly from the social-effects model developed at the beginning of this section. The fourth area is developed from this model when abatement is eliminated. The fifth area approaches the problem differently. Although the objective is still to seek boom levels that are acceptable, this final study would examine the experience gained in previous situations to uncover the existence of any undesirable events that may not already have been associated with the boom, and to determine how estimates of public reaction, including complaints and damage claims, may have influenced authorities to place restrictions on military supersonic flights.

Research in these five areas is designed to carry the overall investigation as far as possible without actual aircraft flyovers. We know from previous studies that certain important responses to the boom cannot be reproduced in the laboratory, but can only be elicited *in situ*. For example, the Oklahoma City study found that three beliefs strongly mitigated annoyance with the boom: a) belief that the SST is absolutely essential to the welfare of the United States; b) belief that sonic booms are unavoidable, local necessities; and c) belief that sonic booms do not cause damage to persons or property (Borsky, 1965, Vol. 1, p. 4). We expect that eliciting these beliefs in full force will be very difficult both in the laboratory with simulated booms and in the field without any booms. Even more compelling is the recent Tracor (1969) finding of the strong, reinforcing effect of involvement with property (in terms of ownership and the value of property owned) on annoyance and on the probability of complaint. Although we are not recommending additional, actual overflights as a sixth and culminating area of research, we do conclude our report with some considerations that are relevant to another overflight program.

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B. MEANING, ATTITUDES, AND INDIVIDUAL DIFFERENCES

Recommendations for research in this section are derived largely from the findings of the three major sonic boom surveys that have been conducted in this country to date (Nixon and Borsky, 1966; Borsky, 1965; and Tracor, 1969). The recommendations, in contrast to previous studies, are based on a more complete conceptualization of attitudes and a multivariate approach to analysis.

Our conceptualization of attitudes, drawing heavily from Krech *et al.* (1962, Chs. 5-7), is that attitudes are complex concepts used to evaluate an object, a person, or anything of which the individual is aware; the evaluations take a cognitive form as beliefs, an affective form as favorable or unfavorable feelings, and a conative (action-oriented) form as tendencies to act positively or negatively. One function of these attitudes is to stabilize the individual's relationship to his world. The attitudes themselves are shaped by the usefulness of the objects in satisfying an individual's wants, by his relevant information or experience, by the standards of the groups with which he is affiliated or to which he looks for guidance, and by his own personality. Attitudes change with changes in these "shaping" factors.

Annoyance is an attitudinal concept that is strongly saturated with negative feelings. As the central attitude in evaluating sonic booms, annoyance is strongly influenced by the shaping factors mentioned above. Other influences come from closely related attitudes and beliefs that concern the source of the boom, the agencies that might control the boom, and the effects of the boom on the person and his possessions (Borsky, 1965). Again, these related attitudes are influenced by the shaping factors: want fulfullment, information and experience, group attachments, and personality.

Recommended Research

This view of annoyance as an attitudinal concept should be developed in two research units. The first unit should consist of further analyses of data from previous surveys with the aim of extracting criteria for judging the validity of simulation studies. The second unit should consist of laboratory tests of simulation and the comparison of results with the criteria developed in Unit 1.

Unit 1. Further analysis of data from previous surveys

Previous surveys to be analyzed are those of St. Louis (Nixon and Borsky, 1966), Oklahoma City (Borsky, 1965), and a recent multi-city study for which there are only tentative reports (Tracor, 1969). The immediate objective of this unit would be to construct indices of the individual characteristics and attitudes that

correlate with annoyance. All three of these studies show a lack of information about one or more of these variables; for example, there is a lack of information in the Oklahoma City study about those attitudes commonly associated with socio-economic status and, in the more recent Tracor study, about those involving group membership and communication. Furthermore, analysis in these surveys is largely confined to contingency tables, which usually compare only two variables. However, by using multi-variate analysis, we hope to reduce further the data of each report and to isolate the more crucial variables.

The result of such analysis should be a series of variables with appropriate measures that correlate with annoyance in the field. These measures can be used in Unit II to determine whether annoyance induced in the laboratory, or in other simulated conditions, is similar to annoyance as measured under field conditions.

There may, of course, be other benefits from this study, including additional substantive findings from existing data, and the ability to impose a theoretical structure (such as the concept of attitudes outlined above) on the data.

The contractor should have experience in the analysis of complex survey data.

Unit 2. Simulation of annoyance

Although the correlating indices developed in Unit 1 will be much more detailed and better scaled than those now obtainable, we can anticipate on the basis of existing reports what some of these major indices will be. We expect verification of the three beliefs cited in the Oklahoma City survey (Borksy, 1965), of the correlation of socio-economic status and annoyance from the multi-city survey (Tracor, 1969), and of the concern with property damage cited in all three surveys.

The purpose of Unit 2 is to determine whether the annoyance from simulated booms under artificial conditions will vary with the correlates of boom-induced annoyance as well as with the magnitude of booms. The correlates will be those established by Unit 1 as affecting annoyance in field situations. The study should use a standard, simulated indoor boom of an intensity sufficient to produce startle, but not to induce trauma. Measurements should replicate as closely as possible those used in the field; all annoyance scales as well as the correlating indices identified in Unit 1 should be examined.

Subjects should be chosen to represent extreme cases on the correlated dimensions, that is, persons of high and low economic status, of high and low involvement with property, of high and low belief in the inevitability of the boom, and so forth. Instructions to the subjects should be manipulated until the

correlation of annoyance with other factors resembles that found in the field or until the effort is established as probably hopeless.

If correlates of annoyance can be reproduced in the laboratory, then we assume that the concept of annoyance and the exploration of the attitudes, meanings, and individual differences that condition annoyance can be profitably pursued through further laboratory studies. If, however, laboratory-induced annoyance is not accompanied by its known contextual correlates, then further effort should be limited to refining the measurement of known correlates and standardizing them on known criterion groups.

The contractor should be qualified to conduct psychological laboratory experiments, and should have both the equipment necessary to simulate an indoor boom and access to a wide variety of respondents.

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C. FACTORS INFLUENCING COMPLAINTS

Recommendations for research in this area treat complaints as the acts of individuals. Before making our recommendations, however, we distinguish two factors: first, *who complains?* (That is, how do people who complain differ from those who do not?); second, *what do complaint rates mean?* (That is, if one has complaint data, what can he infer about non-complainers?) The first two research projects outlined below are designed to advance our knowledge about the first factor; the second two projects, about the second factor.

Further analysis of the data gathered in the Oklahoma City study (Borsky, 1965) and the recent multi-city study (Tracor, 1969) may reveal even more about differences between complainers and non-complainers. Borsky has established a scale having a zero point of non-annoyance and other points of annoyance, desire to complain, and complaints. The Tracor analysis confirms the existence of such a scale, but presents no data on those who desire to complain but do not. Oklahoma City data show that respondents advance along this scale with time (6 months) and with closeness to ground zero (under a plane's flight path); the Tracor data contain some evidences of higher annoyance and higher complaint rates with increased numbers of supersonic flights. Both studies show that complainers and annoyed persons experience more interference with activities; that complainers are better educated, may tend to middle rather than extreme incomes; and that complainers have greater concern for property and damage than do non-complainers. The Oklahoma City study shows, proportionally, that more complainers are over forty; are women; have more dislikes of their environment; consider their neighborhoods noisier; are more annoyed by noises other than the boom; have a better knowledge of the boom's causes; are less inclined to believe that aviation officials care what happens to them; do not consider aviation, SST's, and booms essential; and beleive that booms damage property. The Tracor multi-city data, however, show that complainers are not more annoyed by other noises (the only contrary finding in the two sets of data); are of higher occupational level; oppose the boom because of its potential damage to property rather than for reasons of fear or annoyance; have definite opinions about the boom; discuss it more with others; and own their own homes. Further, using quite different evidence, both studies conclude that complainers are responsible and reasonable people.

Many of these characteristics also distinguish those who are annoyed from those who are not. In both studies, analyses are dichotomous so that the annoyed are compared to the not-annoyed, those desiring to complain to those not so desiring, and those who did complain with those who did not. This leaves us unable to answer the questions: What distinguishes those who wish to complain from persons who only express annoyance even though they

are (equally) annoyed (and equally exposed)? What distinguishes those who do complain from those who desire to but don't? It could be that beliefs about SST's, booms, and property damage govern annoyance, while discussion with others governs complaint action. Neither of the existing analyses examines these questions.

The multi-city report leaves unanalyzed a score or more of variables that bear on such issues as the respondent's stability in his neighborhood, his participation in group opposition to the boom, his attitudes to the boom and its sources, his beliefs of its inevitability, his organization memberships, and so forth.

The first recommended research unit is further analysis of existing data. The second is an application of the findings and hypotheses about individual differences to existing situations in which complainants can be identified.

The third and fourth units examine the differences between complaint situations that influence complaint rates. Unpublished data in our files indicate that complaints quadrupled at one airport within a year; this increase occurred without substantial changes in either affected persons or aircraft operations. What seems to have changed was hope for abatement and knowledge as to where to complain. The fact that elements inherent in the complaint system can influence complaint rates calls for reconsideration of comparing two locations to each other or a single location at widely different times.

Borsky was able to link complaint rates to distance from the ground track, just as unpublished aircraft noise complaint data show complaint rates to be accurate indicators of composite noise levels. We may be able to make valid comparisons within areas having the same complaint system, but not between areas with different systems, at least not until we know how to allow for differences between systems.

Though we know that complaint rates vary with complaint systems, we do not know the parameters of this variance, nor shall we have a firm grasp of complaint rates as social indicators until this variance is better understood. The third and fourth units are intended to increase this understanding. Since the problem of complaining is not confined to sonic booms or to aircraft noise, a number of agencies would be logical sponsors for any of the following studies.

Recommended Research

Unit 1. Further analysis of existing data

The objectives of this analysis are twofold:
(1) to assess data for four categories of respondents (controlling on strength of stimulus)

a) non-annoyed,
b) annoyed not desiring to complain,
c) desiring to complain but not complaining, and
d) complaining;

(2) to use both analyzed and unanalyzed data to characterize these four categories of respondents in terms of

a) community orientation, i.e., stability, activity, organization and group membership, socio-economic status, and categorical status (age, sex, etc.);
b) boom orientation, i.e., knowledge, beliefs (including beliefs about options), attitudes, communication (personal and through mass media), and activities interfered with; and
c) personal orientation, i.e., noise sensitivity, complaint activity, and orientation to property.

Analysis should produce further findings and hypotheses about characteristics that may distinguish the four categories of respondents.

Not only should the Oklahoma City and the multi-city data be used, but also the data from a community study of air pollution in the St. Louis metropolitan area (Schusky, 1965). This last study contains the data necessary to classify respondents into the four categories named above, the data covering their sources of information, discussion, attitudes toward pollution, etc., and air-pollution measurements that provide rough control of exposure.

Contractors should have experience in the analysis of complex survey data.

Unit 2. Test of hypotheses concerning individual differences in complaining behavior

This unit consists of a field study at two sites for the purpose of validating the hypotheses from the analysis recommended in Unit 1 above. The objective of this study is to differentiate between complainers and non-complainers at both sites in terms of individual differences. Such differentiation cannot be reliably made with existing data, because previous studies were not designed to test explicit hypotheses. For example, although there are over 350 complainants in the multi-city study, they cannot be classified by strength or frequency of boom. In the Oklahoma City boom study and the St. Louis air-pollution study, we can categorize complainants by strength of stimulus, but in each study we have only 100 complainants to categorize.

Since this study will attempt to generalize complaint behavior *per se*, complaints need not concern sonic booms. Sites will require records so that complainants — presumably to aircraft noise, air pollution, or other noxious stimuli — can be identified by address. Procedure will aim at identifying and interviewing

complainers who are exposed to different stimulus levels and at matching complainers with non-complainers from the same stimulus levels. This matching should be achieved by drawing the non-complainer sample from the same levels of stimulus strength, but otherwise randomly from the affected area. Pairing on other variables, e.g., drawing from the same city block, may mask such important differences as status or neighborhood. Drawing a larger non-complainant than complainant sample may be desirable. Approximately 100 complainers are required in each stimulus-strength category at each site (300-500 complainers per site). Two sites should be used to insure the absence of situational artifacts.

In this case the analysis used in the first study should be replicated; variables such as ethnic origin, identification with the neighborhood, and residential stability should be added; and each of the groups of complainers and non-complainers should be analyzed across stimulus strength. At low stimulus levels those who complain may well be largely chronic complainers, but this preponderance of chronic complainers may tend to disappear when the rate reaches a certain level. In other words, this technique should reveal how individuals of different characteristics are "recruited into" the several categories.

The contractor should have a survey research capability. The study above is prerequisite to this unit.

Unit 3. Constructing a model for complaint behavior by means of laboratory studies

The purpose of this study is to analyze those antecedents of complaining that do not depend on the strength of the stimulus nor on individual differences among people, but rather are inherent in the situation itself. These antecedents include costs of making complaints: in finances, in effort, in foregoing other activities, in psychic terms (such as the dislike of being critical), and, possibly, in social terms (such as neighborhood opinion); and the quantity of abatement anticipated, time until action is taken, and probability that action will be taken. There may also be intrinsic satisfactions for those who complain. For example, complainers in Oklahoma City were found to feel that they have a right or even an obligation to complain (Borsky, 1965, Vol II, p. 290). Depending on the community setting, there may also be social rewards for complainers; the Oklahoma City study finds people who say they would complain or who complain in more difficult (costlier) ways if asked to do so by a neighbor (Borsky, 1965, Vol II, p. 145).

The complexities of these factors would seem to require exploration through laboratory techniques in which many dimensions may be explored with many subjects. Possible techniques are role playing, laboratory simulations, and paper and pencil tests.

The outcome of the study should be a model of the situational factors that affect complaint rates, particularly factors that characterize the complaining institution in terms of its complaint system and the possibilities for abatement. The model should be capable of being tested in a field survey.

The contractor should have capabilities in test construction and human laboratory testing, together with some minimal psychophysical capability to insure control of the stimuli presented.

Unit 4. A comparative study of complaint systems

This study has two major objectives: the first is to test the model of complaint behavior developed in Unit 3 above; the second is to compare different systems for handling complaints. For both objectives, the dependent variable will be complaint rates, but in the second study, another important variable will be the usefulness of complaint data for organizational administration.

Because complaints and complaint rates are employed as a social indicator, this unit should develop the uses and limitations of complaints as indicators, the considerations for complaint management, and the usefulness of complaints to the organization that is causing the difficulty.

From the standpoint of research strategy, the crucial problem is to stabilize the complained of stimulus, to randomize individual differences, to vary the ways in which complaints are handled, and to measure complaint rates. These requirements for a research design can be met by a study of airports with different methods of handling complaints and different policies for noise abatement. We propose the study of twenty airports, sixteen civilian and four military.

An organization study should be made of the complaint system at each site, including an examination of pilots' and operators' reactions to the system and an examination of complaint files. At each site 300 nearby residents, of whom 100 to 150 would be complainants, should be surveyed. Complaint rates should be compiled by noise areas.

The complaint system should be viewed as a communication channel and should be tested to assess the quality of information produced, some of the costs to the complainant, and the uses made of information by the airport. Records should provide a basis for sampling complainants who would be matched with non-complainants in a sample design like that in Unit 2 above. The objective of questioning nearby residents is to examine their perceptions of the dimensions developed by the model. However, the model should also be tested by examining relevant parameters of the complaint system itself, such as difficulty of complaining and probability of abatement.

In summary, this unit should test a systematic model of complaint behavior and compile and analyze the complaint experience on one type of organization (airport), including the pressures of complainants and the backpressures of those whose behavior was likely to be influenced (pilots, operators).

Since each airport's complaint system is the essential object of analysis, one needs a number of airports in order to produce variation among the independent variables. The possibilities for one or several contractors are apparent.

Contractors must have capabilities in both organizational and general surveys. This study should follow the study outlined immediately above.

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D. FACTORS INFLUENCING GROUP ACTION

The difference between individual complaints and group protest has long been an important distinction in the analyses of human reaction to aircraft noise. "Vigorous community action" was listed as the most extreme reaction to noise when the composite noise rating (CNR) was first used to predict community reactions (Stevens *et al.*, 1955). When the CNR was adapted to the effects of aircraft noise on a community, the reaction scale used was one of virtually no overt reaction, individual complaints, or community action (Stevens and Pietrasanta, 1957). Subsequently, Galloway and his colleagues tested this scale by investigating aircraft noise complaints in 21 communities, differentiating them into individual and group complaints and calculating the prevailing aircraft noise ranges in the communities. While the data are not unequivocal, Galloway and Von Gierke (1966) estimate the dividing line between individual complaints and community action at a CNR of 110. In our view of the relationships between boom exposure and social effects (Fig. 5) the onset of the "critical mass" phenomenon — the point at which reaction increases markedly with increased boom exposure — is also the region in which group protests start to increase much more rapidly than do individual complaints.

Group action is highly visible, tending to engender a commitment to the position of the group and representing a validation (hence a reinforcement) of the individual's own attitude. Voluntary groups, whose purpose is to advance issues, also form focal points for the attitudes of nonmembers and rallying points for intensified action when crises arise. The formation of issue groups entails social costs that can be of a serious magnitude; the transition from individual dislike to formation of an "anti" group represents a change in the social structure; it turns individual disagreement into a social conflict of some level of intensity. While anti-boom groups may form in mere anticipation of sonic booms (Shurcliff, 1969), we must allow for a boom level at which conflict may rise to a height that is devastatingly costly to society.

Direct estimates of the boom levels at which protest groups will begin to form in appreciable numbers are very difficult to make, because we do not have studies in which boom strength and the intensity of group membership covary. Thus, we recommend that existing data be probed for any clues to this relationship, especially since it is the relationship central to our concern.

The Oklahoma City experiment reported that by the end of the six-month's study "local groups were urging individual complaint" (Borsky, 1965, p. 240), but gave no details concerning this activity. The multi-city study questioned respondents about their participation in group activity, but reported no data in the analyses and did not measure boom strength (Tracor, 1969).

Not only do we lack data about the boom levels at which individual behavior becomes group behavior, but we know relatively little about the conditions under which individuals band together for common purposes, accepting the costs of group discipline by doing so. The problem is an old philosophical one; theories vary from Rousseau's "social contract" to Durkheim's proposition that man in his prehistorical state was a group creature and became individualized as civilization advanced. However, the problem remains that, while we understand the growth of group attributes once groups are formed, modern social science knows little about the conditions under which groups form. This lack of data suggests that we must resort to empirical studies of the most similar situations we know: namely, group opposition to aircraft noise and air pollution.

Residents of certain areas around airports are strongly organized against aircraft noise, while residents of other areas near the same airports with similar exposures are not organized. Comparative studies of these types of areas may help us to understand the conditions under which people might be expected to organize against the sonic boom. The general model presented earlier in Fig. 4 suggests where to look for conditions that would result in group rather than individual complaints. The model indicates that a public opinion and a certain density of persons willing to act are necessary substrates for group protest.

In the model, symbolic meaning is the group correlate of individual (personal) meaning. Symbolizing is important because symbolized meaning can be more easily handled and circulated by individuals than can vague associations. Thus one sonic boom may be commonly understood to be a military necessity, while another boom may represent civilian indifference. Some such symbolization is necessary to explain the greater acceptability of military-generated booms in St. Louis (Nixon and Borsky, 1966).

Public opinion, in our model the social correlate of individual attitudes, is a group evaluation of an object when attitudes towards that object are common, shared, and symbolized. The presence of such an opinion greatly lowers the cost of group action that is consonant with the opinion. Under these conditions the group is supported by, rather than being in conflict with, its immediate environment; further, because the opinion is shared, the support is manifest.

The second substrate for group action is a density of complaint potential. When individuals at a given state of readiness are socially cohesive, we may anticipate social action. Social density is more than physical closeness; interconnectedness or social interaction is a second dimension of that density. An inquiry concerning organized and nonorganized complaint, therefore, would seek differences in public opinion, in the physical density of persons ready to act, and in the relatedness or interaction of

these persons. It may be that the extent of public opinion and the density of persons ready to act are strongly influenced by such factors as socio-economic status, stability of the community, and the community's general state of organization.

Recommended Research

Further Analysis of Existing Data

Those questions in the Oklahoma City study indicating that the respondent or some member of his family helped to set up a citizen's committee to do something about the sonic boom (Borsky, 1965, Vol. III) should be included in the further analysis of existing data to determine whether the responses "scale" with annoyance, desire to complain, and complaint. Similarly, the questions in the multi-city report on cooperation with other persons and affiliation with active organizations (Tracor, 1969, Vol. IV) should be added to the scale. The air pollution study previously recommended for further analysis also includes questions relating to group activity.

The analyses recommended here can be made as part of the analyses of existing complaint data (Sec. C, Unit 1) without adding appreciably to the level-of-effort for that unit. We have, therefore, chosen not to identify this study as a separate unit.

Unit 1. An attempt to plot organizational membership by boom levels

The purpose of this unit is to attempt a reconstruction of the organized activity in Oklahoma City and to assess the relationship of this activity to distance from the flight path. The first phase of the study should be an informal exploration of the city to determine the nature or character of group activity during the 1964 sonic-boom experiment and any existing documentation of that activity. The second phase should be the design of a study that is based on data mapping the residences of organized complainers or mapping their activity relative to boom strength during the 1964 experiment. This phase should also attempt an assessment of those characteristics (as of 1964) of organization members that could be compared to the characteristics of others who responded to the NORC survey. The third phase would be data gathering, and the fourth would be analysis of that data.

The success of this recommended study is uncertain. However, the value of the study lies in the possibility that it may provide an approximate relationship between the level of organized protest and boom levels.

The findings of one phase will condition the level-of-effort that is possible for the following phase. Since this study has a low probability of feasibility but a potentially high pay-off, authorization might be given for four man-months to cover the first

two phases, with a contingency item of eight man-months to finish the study if feasibility has been demonstrated. The contractor should have professional qualifications in research on community organizations and capability in field surveys.

Unit 2. A study of organized and unorganized communities

The purpose of this unit is to determine the differences between communities or neighborhoods that form abatement organizations and those that do not organize even though the noxious conditions are similar. The study is divided into three major phases, which could be performed by separate contractors.

Phase I should identify the location of abatement organizations and of neighborhoods and communities with similar levels of degrading stimuli that are not organized (or where organizations are essentially inactive), but in which individuals complain with some frequency. Examples in the aircraft-noise field are the active East Boston organizations vs. the dormant Winthrop organization (Logan Airport), and the community action in Nassau county vs. individual complaints in Queens (Kennedy Airport). Similar site-pairs may exist for air pollution. The first-phase task is to develop definitive criteria for such sites, to locate five to twelve site-pairs, and to describe each in terms of the criteria.

Phase II should be a comparative study of neighborhood or community structures. The purpose of this phase is to diagnose differences between organized and unorganized communities or neighborhoods. The data to be gathered are characteristics of the communities or neighborhoods *per se*. These characteristics should be assessed by interviewing informants and consulting existing records. The inquiry should include determining the origin and development of organized protest and attempting to relate the historical information to the nature of the community.

Phase III should be a survey of community residents, sampling residents at each site-pair; the sample for the organization site in each pair should be enriched with organization members. Members and nonmembers should be compared within the organized community and these two categories compared with residents of the unorganized community.

Actually, Phase I should be completed before any other work is undertaken, but Phase II and Phase III should be distinct approaches in each site-pair. We suggest that site-pairs be studied serially, making intensive studies of two sites at the beginning, and, perhaps, doing so simultaneously. This method should result in a series of hypotheses that explain the presence of an abatement organization in one community and its lack in another. These hypotheses should be tested on a third community, refined, and tested on a fourth, then on a fifth. We anticipate that the studies of

communities after the first two will be limited to those variables about which hypotheses are generated; therefore, these studies will be shorter and less time-consuming than the original pair. The ideal method would be to continue adding site-pairs until some hypotheses are verified.

In Phases II and III, inquiry would concentrate on factors most relevant to public opinion and density. Important determinations in Phase II are the degree of organization of the community, the physical density of persons affected at highly noxious levels, the media of communication, the level of news and commentary about the noxious stimulus, etc. Phase III should determine the individual linkages of individuals with their communities and the state of their readiness to act. The purpose of Phase III is to assess individual ties to the community (or neighborhood) structure and to validate the strength and viability of the structures found in Phase II.

Qualifications for contractors are: Phase I — organization with community survey (including records survey) capability; Phase II — anthropologists, sociologists, or political scientists with community survey background and organization with survey capability; and Phase III — social psychologists or sociologists specializing in community organization with survey capability.

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E. A PROGRAM OF RESEARCH DESIGNED TO EXPLORE RELATIONS BETWEEN SONIC BOOMS AND ALIENATION FROM THE LARGER SOCIETY

The fourth area for investigation that grows out of the general model is that of the effects of unabated annoyance on the structure and vitality of the larger society. We propose to measure these effects in terms of alienation. The model assumes that the larger society is the source of the boom and, therefore, has control over it. It assumes that if individuals who are annoyed by the boom have no influence on the larger society, through complaining or by other means, that their annoyance will find some other outlet. We hypothesize that one important way in which people react is to turn against the source of their annoyance. Tests of this and related hypotheses are the concern of the program of research recommended in this section.

When the possibility of abatement is removed, the social-effects model of Fig. 4 becomes the modified model of Fig. 6. Individual complaints become alienation, a term we discuss later, and group protest finds its outlet in the formation of "anti-" groups. The line of research recommended in this program may be more important and more relevant to the potential effects of the boom than the three programs suggested above. On the one hand, many signs of environmental degradation appear around us, and on the other, many signs of a turning against the central values of society are evident. These two trends may not be importantly related, but some relationship *does* exist between them. The issue demands attention because at some point a separation between people and the social structure that unites them becomes a point of no return.

"Turning away from the system" means the rejection of an important part of the system's values. This process takes a number of forms. Mentioned earlier were attempts to influence society as in reform or revolt on the one hand, and forms of withdrawal on the other. The program of research recommended here primarily examines *withdrawal,* particularly feelings of powerlessness and the feelings of separation from society that these engender. Previous research has raised the question of the amount of active opposition generated by sonic booms, but no research program has tried to assess either the amount or the consequences of passive opposition.

We shall assume a paradigm that relates the individual to society. In this paradigm, an individual's failure to influence a social system of which he is a member leads him to a feeling of *powerlessness.* If chronic, this feeling can lead to *alienation,* defined here as a feeling of separation from the system. This separation leads to a *lowering of identification* with the system, defined here as a lowering of value congruity between the individual and the system. The key variable that we shall use here is

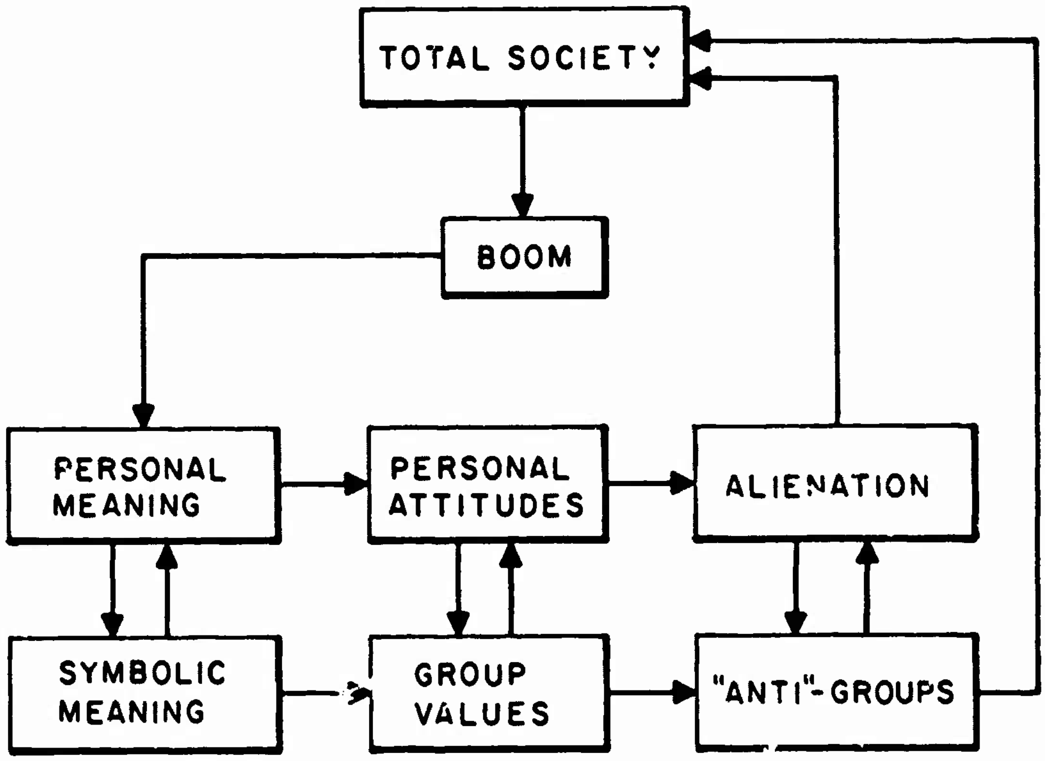

FIG.6 A SOCIAL-EFFECTS MODEL WITHOUT ABATEMENT

alienation. This variable does not completely define either system strength or individual attachment. Alienation says much about the "social fabric", that is, the linkage between discrete individuals and the social system, but little about the framework of the social structure or about its functioning, both of which are important to a system's strength. Similarly, alienation says a great deal about the feelings of an individual *vis a vis* a potential source of his identity, but little about his dependence on the system or his contribution to it, both of which are important aspects of the strength of his attachment. However, alienation is an important phenomenon conceptually, and it can be measured (Davids, 1955; Dean, 1961; Nettler, 1957; Scrole, 1956). In a recent laboratory study, long-term effects of noise were intensified when subjects had no control over the noise source. Their performance on a task requiring close attention was poorer, their tolerance for frustration was lower, and their irritation was greater than subjects who did have the option of controlling noise (Glass *et al.*, 1969). The program of research recommended below is based on the hypothesis that as powerlessness and its consequent alienation increase, the boom will be less tolerable. A second hypothesis is that if booms are propagated at annoying levels and the people annoyed are powerless to influence the noise, alienation will result.

Before outlining the studies that we are recommending, we should note that the issue around which this program is built has application to other aspects of our national life than the sonic boom. We are dealing here directly with the "common weal". But the fact that the issue is large does not make it less germane to the problem of setting permissible levels for booms.

Three units are recommended below, a survey study and two laboratory studies. The survey is designed to determine the level of alienation that exists in the nation *vis a vis* the social system. Essentially, this measurement will give the administrators who prescribe sonic-boom criteria a baseline, that is, a description of the conditions that their decisions might affect. The survey will answer the question, "How much alienation do we have now?" The second unit is a laboratory study that measures the effect on alienation, if any, of varying the degree of abatement. The purpose of this unit is to confirm the existence of the alleged relationship between alienation and the ability to produce abatement.

The third unit is a laboratory study that investigates the effect of level of alienation on level of annoyance. Essentially, this unit establishes different levels of alienation, administers an annoyance perpetrated by the system with reference to which alienation is measured, and investigates whether or not the level of alienation influences levels of annoyance under these conditions. This study is designed to give evidence regarding the consequences of annoying populations who are at different stages of alienation.

Thus, as in other recommended programs we attempt to measure the costs of the sonic boom to individuals, so in this program we attempt to measure the costs of the boom to the social order. We propose a survey that estimates the degree of alienation of people throughout the country. The results obtained from special groups, i.e., those known to be alienated and those known to feel that they participate in the large society, will determine reference points for other segments of the population. We can then determine whether, for example, the average of the country is close to the extremely alienated or close to those who feel they participate fully. Given these data, an administrator can better judge the risks to the country's welfare of a decision that might result in an aversive stimulus for which there is no abatement. If alienation is already at a high level, the government can probably ill afford to allow it to go higher, whereas if it is at a low level, the benefits of the SST may well be worth the risk of increasing the alienation.

We propose a laboratory study that will determine whether or not a group structure is weakened (alienation is increased) by an assault of aversive stimuli for which there is not abatement. Then we propose another laboratory study that will determine whether alienated people are more annoyed by aversive stimuli than people whose feeling of participation is high. If this experiment shows that annoyance varies with level of alienation, then an administrator can estimate from the results of the alienation survey whether or not annoyance reactions will be exaggerated.

If, at the end of the research program recommended in this report, a field study is carried out with actual booms, then the consequent alienation, if any, can be related directly to boom levels.

Recommended Research

Unit 1. Study to assess the national state of alienation

Before setting permissible levels of sonic-boom intensity, an administrator should know the degree of alienation (or separation) that currently characterizes the nation. It is true that we have no criterion to indicate the level at which alienation may lead to a fundamental change in the society itself, nor do we have criteria that relate levels of alienation to levels of social efficiency. Nevertheless, a national measurement of alienation would illuminate the problem and would locate the sectors of the society in which the problem may be serious.

Such a survey can be planned either as a straightforward inventory of alienation, or (by tapping people's attitudes about various aspects of the national order) as a diagnosis of the areas of concern that produce alienation. Similarly, the survey may be either a national sample to give a picture of "the nation as a whole" or an assessment of alienation among several subsamples,

for example, youth, suburban dwellers, blue-collar workers, and so forth.

Although such an inventory would be of crucial interest to the administrators who are responsible for setting criteria for booms, it would be of equal interest to other policy-making administrators, and legislators as well. The breadth of the survey in terms of areas of inquiry and populations sampled should logically be determined by the number of agencies that would plan to use its results.

Under any circumstances, the survey should be nationwide and be based on a random sampling model. If special populations are isolated for study, an oversampling of the target subsamples (strata) should be planned. Face-to-face interviews should be used and, if attitudes concerning various aspects of the society are measured along with levels of alienation from it, an analysis of the data using computer-based, multivariate, statistical programs should be employed.

There is doubt that a program of this importance, with demands for high-quality performance in a variety of fields, should be left to a single contractor. Rather, we suggest a research structure involving a coordinating contractor with subcontractors to carry out the work, and a review board that would certify the work. The coordinating contractor should have a behavioral-science staff with experience in social surveys and the construction of psychological tests and with substantive background in public opinion or political organization. The review committee should be composed of practicing behavioral scientists chosen for professional competence in the various facets of the study, for example, the conceptualization and measurement of public opinion, public opinion formation, social organization theory, the construction of psychological tests including attitude scales, and political organization including the relation of citizens to governmental structure. Their function would be to act both as professional consultants to the coordinating contractor and as a professional review board; their approval of the survey report might well be required as a condition for its acceptance by the government. Other functions will be clarified, as we develop the several phases of the study and define qualifications. The entire study might well be directed by a group such as the National Academy of Science.

Phase I: Preplanning will designate and assemble the coordinating contractor and the review committee. Together they will outline the detailed objectives and broad procedures, including a timetable, for the study.

Phase II: Planning involves the detailed planning of the project including the selection of subcontractors. Procedures for drawing the sample, including subsamples, will be completely

specified. The interview protocol will be completed. Detailed plans for analysis and reporting will be drawn. If levels of alienation are to be correlated with attitudes, hypotheses concerning these relationships will be made. This phase will be executed by the coordinator with considerable consultant assistance, including persons other than those on the review committee.

Phase III: Pretest will probably use scales for measuring attitudes and alienation that already exist rather than newly-formulated ones (Davids, 1955; Dean, 1961; Nettler, 1957; Scrole, 1956); however, some further validation on predictor populations may prove desirable. That is, measures of alienation may need testing on groups known to be alienated (e.g., "flower children", vagrants) and known to be integrated (e.g., legislators, business executives). Attitude scales may need similar testing. Any of the scales contemplated for use may need modifications as a result of these tests.

This pretesting of scales on criterion groups will serve a very useful purpose in the analysis of the data. In introducing this study, we pointed out the difficulty of relating the data to societal changes or efficiencies. If we know the "alienation scores" of groups that are actually separated from the society and groups that are closely integrated into it, these scores will provide us with reference points to which we can compare the scores of the total population or of subpopulations whose degree of separateness from the society is not known.

After scale testing, the entire interview should be pretested and the pretest data analyzed by means of the statistical procedures that are planned for the final analysis.

Phase IV: Sampling should be performed by a subcontractor who has developed a national sample pattern. The subcontractor will need to draw special subsamples of criterion groups used to validate scales in the pretest phase; he will also need to draw stratified subsamples if the reactions of special subpopulations are to be part of the study.

Phase V: Interviewing should be carried out by a subcontractor with an established, nationwide staff of interviewers. They will be trained for this study by the coordinating contractor and members of his immediate staff. This latter group should be available to answer interviewer questions on a daily basis.

Phase VI: Coding and Transcribing will depend for its complexity on the degree to which the interview protocol uses open-ended responses subject to content analysis. The task of this phase is to convert interviewer records into machine-readable data. Several options exist for execution of this phase, ranging from subcontracting with an organization that has an established coding

unit to the precoding of protocols and their clerical conversion. Under any system, those doing the coding should have hourly access to the contractor or to his immediate assistants.

Phase VII: Analysis is interpretation that should be performed by the coordinator. Several options exist for managing statistical analysis and computer processing. In all of these, options for the coordinator to "follow where the data lead" should be built into the procedures.

Phase VIII: Reporting should be executed by the coordinator. His report should have the concurrence of the review committee.

The coordinator should be a behavioral scientist of high professional standing and experience in the complete conduct of sample social surveys. He should have one or two professional assistants as well as office assistants and ready access to professional colleagues in the disciplines relevant to this study. Members of the review committee should be reputable authorities in their specialties. The sampling subcontractor can be a marketing research or public-opinion polling organization, or a university that maintains a national sample. Any such subcontractor would need a sampling staff capable of identifying special populations and devising procedures for sampling them. The interviewing subcontractor could be any of the three types of organizations mentioned above that maintains a national interviewing staff. If a complex protocol is maintained, one would want to evaluate the training and experience of the interviewers. A coding subcontractor would be used when one needed a staff with experience in content analysis. The coordinator would also need the assistance of one or more statisticians, computer technologists, and editorial assistants.

Unit 2. A study of the effects of successful petition for abatement of an environmental insult on identification and alienation

We propose an experimental test of the hypothesis that identification will be stronger and alienation will be less when members of a social system can influence the annoyance caused by the system than when they cannot. The requirements for testing this hypothesis will be outlined below, but the actual design of the experiment is left to the experimenter.

The experimenter shall conduct a social-psychological experiment in which subjects shall be members of an organization (naturally or by artificial induction) with which it is possible for them to identify. This organization, in turn, shall subject them to an annoyance. The subjects will be informed that this annoyance is the unintentional by-product of a process that yields benefits for the social system. However, these benefits are no more (nor less) available to them than to people who are less subjected to the annoyance or not subjected to it at all. Conditions shall be created

so that before being subjected to the annoyance, subjects shall have high positive identification with the social system within somewhat narrow limits of variation. They shall be tested for identification (adoption of the system's values) and for feelings of power *vis a vis* the system, and for alienation (feeling of separation from the system). These conditions shall hold for all subjects.

The independent variable of the experiment is the ability of the subject to abate the annoyance. Recommended here is a complaint procedure of sufficiently high cost that some subjects will take advantage of it and some will not, although all to whom the procedure is available will know of its existence and of the costs it entails. Partial abatement will be given one-half of those who complain. For another group, no complaint procedure will be available. This will create four experimental conditions: complaint with abatement, complaint with no abatement, opportunity to complain with no abatement, and no opportunity to complain nor any abatement. After the experimental manipulation, subjects shall be retested.

This will enlighten such questions as whether it is important that people complain or just that they have an opportunity to do so; whether people "turn against" an organization when their complaints are futile or when they cannot complain at all. It will indicate these and similar differences both for their effects on identification and for their effects on alienation. These findings may help demonstrate conditions that produce rebellion and apathy, respectively.

A qualifying contractor would have the capability of designing and conducting social-psychological experiments.

Unit 3. A study of the effects of levels of alienation on the acceptability of an environmental insult

The purpose of this study is to answer the question: Does the level of alienation that people feel affect their tolerance of environmental insult by a social system in which they have membership? If the answer to this question is affirmative, then the level of alienation that people feel will influence their tolerance for booms and, presumably, their other reactions to them.

Recommended here is an experiment using the above question as a hypothesis. The requirements of the experiment will be outlined here, but the actual design of the experiment is left to the experimenter.

The experimenter should first produce conditions wherein subjects will be members of a social system (naturally or by artificial induction) with which it is possible and normal for them to identify. This social system, in turn, will subject them to an annoyance. The subjects will be informed that this annoyance is the unintentional by-product of a process that yields benefits for

the social system. However, these benefits are no more (nor less) available to them than to people who are less subjected to the annoyance or are not subjected to it at all. The experimental subjects shall have no control over the annoyance or the process that produces it. These conditions shall hold for all subjects.

Subjects shall vary along a continuum of identity-alienation *vis a vis* the experimental social system. This variance, which may be realized through induction or selection (but shall be verified by measurement), constitutes the independent variable of the experiment. Tolerance shall be tested in terms of annoyance, reported future willingness to live with the stimulus, desire to complain, actual complaint at some cost to the subject, and efforts to join others in securing abatement.

Corollary hypotheses are that the degree to which a person's values are contiguous with that of a social system is a function of his identification with the social system, that insult by the social system will reduce the congruity of members' values with those of the system, and that the change will be greater for persons in the center of the identity-alienation continuum than for those at either extreme. The study shall be performed in two phases.

Phase I shall use two somewhat extreme conditions of identity-alienation. (This condition will prevent the testing of the corollary hypothesis concerning the change in middle and extreme conditions of annoyance.) Also a condition of high-annoyance level and another of low-annoyance level shall be created. This will require four experimental samples. We suggest that each sample include 30 to 50 subjects and that these subjects include members of both sexes; members of the "youth culture" and established adults; and persons of lower, middle, and upper class background. A balance between the samples on these variables should be maintained. The data from this first phase shall be examined not only for confirmation of the hypotheses but also for effects of extremes of identification-alienation, of levels of annoyance perpetrated, of sex, of youth-established orientation, and of socioeconomic status. Hypotheses concerning the conditioning effects of these variables on the relation between identification-alienation and tolerance for annoyance will constitute part of the Phase I task.

Phase II will test these hypotheses on small groups (10-30) of subjects selected and tested in ways that will provide strong manipulations of the conditioning variables about which hypotheses have been formulated; that is, if sex seems in Phase I to produce differences in tolerance level, Phase II will systematically test samples of men and women.

The results will specify the conditions, if any, under which the central hypothesis can be sustained and will indicate the

segments of the national population that may be differentially annoyed.

A qualifying contractor would have the capability of designing and conducting social-psychological experiments.

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F. RECONSTRUCTION OF EXPERIENCE GAINED IN SONIC BOOM SITUATION

Recommended Research

Unit 1. An historical survey of effects on human beings

The general purpose of research on human response to sonic booms is to link response effects to boom parameters. Many effects have already been reported or predicted. In addition to the effects discussed in the previous sections of this report are reports or predictions of vomiting, asphyxiation, heart attacks, miscarriage, aggravation of headache and ulcers, panic, increase in excitability, decrease in sociability, and accidents caused by sudden motions during delicate operations (Shurcliff, 1969). The extent to which these and other conceivable effects are perceived as real and threatening can be important in determining the public acceptability of the boom. Therefore, we recommend research that can provide positive rather than speculative identification of these effects.

Two general approaches for studying the direct effects of sonic booms on humans are 1) exposing subjects to stimuli that simulate the pertinent features of booms and observing the effects (the approach followed in the recommended research units on specific studies in physiology and psychology) and 2) reconstructing the record of boom effects that occurred during previous instances of boom exposures. Such an historical reconstruction may provide more definitive evidence of the presence or absence of the many effects that have been predicted. This approach is included as a recommended research unit in sociology because it is to be accomplished through a field survey, a method more frequently employed in sociology than in physiology or psychoacoustics.

Sonic booms may produce a wide range of undesirable effects on humans, such as physiological damage, psychological disturbance, and boom-induced accidents. Records obtained during supersonic overflights provide one possible means of exploring the incidence of these effects. The line of inquiry suggested here is purely empirical, being based on the assumption that given the number of accomplished supersonic flights, if damaging events might be expected to occur in the context of relatively common events, they probably have occurred already. While a negative finding can never be conclusive, negative findings from this investigation would, we believe, be compelling; positive findings would establish a basis for estimating the levels at which booms induce such damaging.

Experimental overflights of supersonic aircraft have been conducted in:

St. Louis, 1961–1962. Approximately 50 booms at levels up to 3 psf at the rate of about two a day (Nixon and Borsky, 1966).

Oklahoma City, 1964. Eight booms daily for approximately six months, increasing from 1.1 to 1.6 psf (Borsky, 1965).

Chicago, Dallas/Fort Worth, Denver, Los Angeles, and Minneapolis, 1967. Two to five booms per week for four months at 0.7 to 1.8 psf (Tracor, 1969).

Additionally, training flights of supersonic military aircraft are frequently conducted over sparsely populated areas of the western United States.

The object of this unit is to discover and document situations directly traceable to the sonic booms in which personal injury has been sustained through illness or accident; in which there has been disruption of such events as outdoor concerts and plays or the making of musical recordings, video tapes, or sound motion pictures. Injury to animals and vibration damage to property are within the scope of this investigation only if they, in turn, caused injury to a human being.

Areas where experimental overflights were made, but which at some period have been relatively free of sonic booms, can act as their own controls by using a before-after design. Areas that are routinely subjected to booms and where records are available may have to be matched by boom-free control areas.

While potential contractors will be asked to devise and describe their own methods of investigation, certain possibilities are suggested here: the use of reference groups and persons in key positions - chief surgeons, directors (or other chief officers) of medical staffs, and pathologists at hospitals at the time of supersonic aircraft activity in the community; staff members of unions, trade associations, and large contractors in the building and construction industry; staff members of workmen's compensation units; claims officers for the United States Air Force; persons engaged in delicate, but noncritical, occupations - jewelers and tailors; the claims and complaint files of governmental agencies in areas where sonic booms are or have been prevalent.

Possible contractors are historians, anthropologists, and journalists.

Follow-on projects

If the information gained from these units should be combined with findings from the project on the dimensions of startle, a laboratory study should then be conducted for each type of event to describe the manifestations of startle (dimensions of the startle reaction) that would have minimally triggered the event and the (simulated) boom level that would minimally produce those manifestations. This type of inquiry may be very valuable in prescribing minimum permissible levels of boom.

Unit 2. Studies of the restrictions imposed on supersonic military flights

The units of research recommended up to this point are designed to produce guidelines for setting tolerable sonic boom levels by either examining or predicting the *effects* of sonic boom propagation. This unit is designed to produce such guidelines by direct examination of *restrictions* that have been placed on supersonic overflights.

People normally show a high tolerance for inconveniences arising from military necessity, and most military functions have been relatively immune from regulation. Nevertheless, supersonic military aircraft are prevented from flying over populated areas. We assume that these restrictions are responsive to a concern about the human effects of sonic booms. The limits that military agencies find workable may indicate the boundaries that supersonic transport aircraft ought to observe.

The problem of identifying the considerations governing military policy is delicate and should be approached with caution. Military authorities may be reluctant to reveal the operating considerations upon which flight restrictions are based. It may, therefore, be more fruitful to conduct the studies suggested below within the government.

These program studies must be thorough, if they are to be useful. Basically, investigators should study motivated reactions to public pressures. The basic motives may not be the first ones communicated; hence, a superficial inquiry may be misleading. Whether conducted by persons in government service or by outsiders, the studies should aim for objectivity, and the investigators should acquire a reputation for impersonality as well as for thoroughness. The data needed are: (1) a full report of existing restrictions; (2) a history of boom propagation; (3) a summary of the damage claims, complaints, and protests that the military has received; (4) an account of the effective sources of policy influence within the government; and (5) an evaluation of the social pressures currently felt by the military. These data can be assembled in two phases.

Phase I is essentially a records study of data concerning booms generated by supersonic military overflights of populated areas, and of damage and complaints. It should include projections from flight data and aircraft characteristics as well as data gathered by instruments. The investigators should also examine summary damage claim reports, original and summary complaint records, and correspondence involving complaints and protests, and then construct a coherent record of these data by location.

The contractors should have the capabilities of an historian and an aircraft acoustician.

Phase II is a study of the origins and growth of current military restrictions. A history of policy determination, including a theory of the forces that shaped the policy, should be gathered by interviews and by an examination of correspondence and memoranda. This information should be gathered from civilians who have been active advocates of restricting supersonic military overflights as well as from military personnel. The current status of military restrictions should be determined by an examination of standing orders. Also, an assessment of current social pressures should be made.

The study should be directed by an historian, preferably a military historian. The assistance of persons with news-gathering as well as historical experience might aid the investigation. Finally, a sociologist familiar with organizational communication and decision-making processes, would be invaluable.

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G. CONSIDERATIONS OF A FIELD EXPERIMENT USING SONIC BOOMS

We feel that it is premature to recommend a field experiment to test the effects of actual sonic booms on people in their natural situations. In specifying research to determine permissible boom levels, the logic of conducting a field experiment is unimpeachable, but such an experiment is costly and may prove to be unnecessary. Recommendation of a field experiment is logical because none of the studies above (except those that analyze existing data derived from field tests) relate social effects to booms of varying level. In other words, in terms of the overall research program, the independent variable, boom level, is missing. The only way to produce booms at different levels is through an overflight program. Furthermore, there is considerable doubt that essential effects, especially those that depend on the meaning of the boom and attitudes towards it, can be produced unless actual booms are propagated in actual living situations. (The question of the degree to which these can be reproduced through simulations is the basis for the second unit dealing with meaning, attitudes, and individual differences - Part III, Sec. B).

Although a field experiment would be very costly we can logically defend the advisability of a program of year-long overflights in four locations. We cannot estimate the costs of the overflights themselves nor those of administration. The program of studies of military restrictions on overflights of populous areas may reveal risks of large additional costs in the form of public disturbance and ill will.

Whether or not a field experiment will be necessary depends on how thoroughly the studies recommended above enlighten the issues. The question depends, too, on the balance of political forces surrounding the issue and on the degree to which the adminstrators concerned must base their decisions on direct rather than inferential data.

If a field experiment proves necessary, the associated survey can examine questions much more specific and significant than those examined in previous surveys. The studies recommended here in Sec. III will provide many of the questions to be raised and the methods to be used in a field test; the results of all but two of the research units described would be utilized directly. Moreover, we will know more about the technical nature of booms and their effects on structures than heretofore. Above all, the surveys already carried out have told us where to look for other answers.

Because a field study is complex, expensive, and runs the risk of adverse public reactions, the questions it examines should be directly related to those areas of uncertainty that inhibit decision. If boom levels are doubtful, the level of propagation in the experiment should include and bracket the moot levels. If

long-term effects are the major concern, then the experiment should be long enough to resolve the issue. If special populations are of primary concern, they should be deliberately overchosen in the sample as were complainants in the multi-city study.

In brief, a decision on permissible boom levels should be made, if at all possible, on the basis of past research and the several programs recommended above. However, a sonic-boom field test may be deemed necessary at some future date. By the time the above programs of human research and the parallel studies of propagation and of physical and animal effects are completed, there should (with some additional preparation of measures of meaning and attitudes) be a sufficient body of hypotheses and measurement methodology available for field experiments on any specific issues that are impeding a decision.

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(Contract No. DOT-FA69-WA-2103, Project No. 550-007-00, Report ~~No. FAA-70-2)~~ FAA-NO-70-2
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